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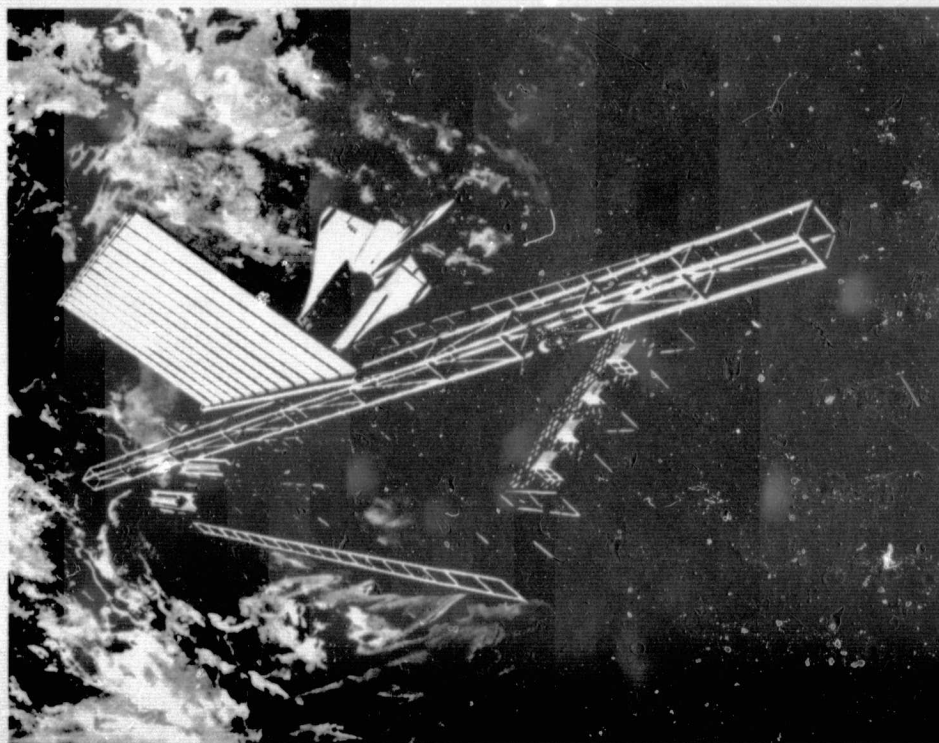
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ORBITAL CONSTRUCTION DEMONSTRATION STUDY

VOLUME I EXECUTIVE SUMMARY

FINAL REPORT

(CONTRACT NAS 9-14916)



GRUMMAN

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CONSTRUCTION DEMONSTRATION
STUDY**

**VOLUME I
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FINAL REPORT

(CONTRACT NAS 9-14916)

Prepared for

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Section 1

INTRODUCTION

1.1 STUDY SCOPE

The exploration and utilization of space has witnessed a continuous growth in spacecraft size and weight. Many applications are now envisioned which require ultra-large structures for implementation. The "Outlook for Space" study and the Aerospace Corp. "Study of Commonality of Space Vehicle Applications to Future National Needs" have identified potential new space initiatives (some of which are listed in Figure 1-1) requiring ultra-large structures that would serve a wide range of human needs. These ultra-large structures, due to launch vehicle payload and volume limitations, will require some form of space fabrication and assembly. The objective of this study has been to analyze the structural, fabrication and assembly requirements for these new initiatives and define a flight program that provides the technology base and construction capability for embarking on these ambitious future programs. Construction issues were identified and those needing space demonstration and test to advance technology were included in the flight program.

OBJECTIVES

- ACQUIRE ABILITY TO BUILD LARGE STRUCTURES IN SPACE
 - SOLAR POWER
 - LARGE ANTENNA
 - ILLUMINATORS
 - ETC.

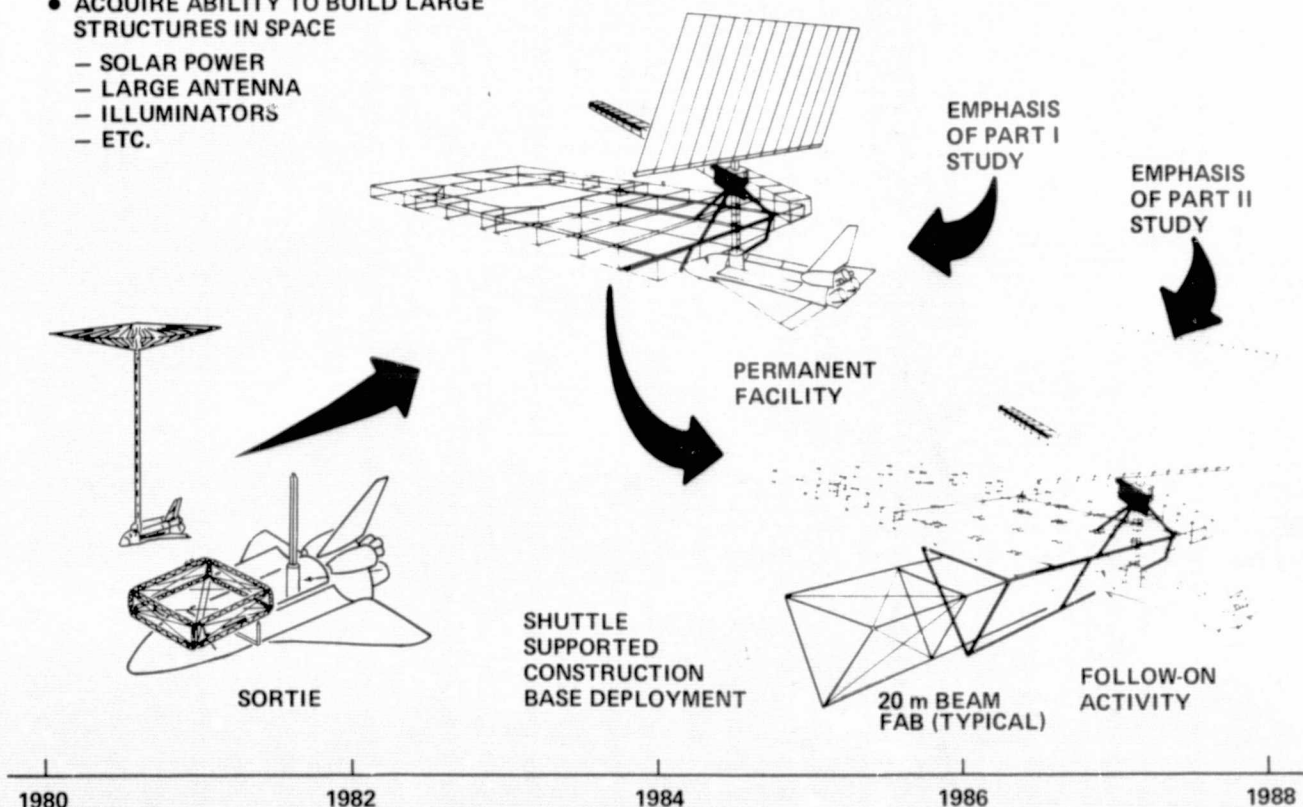


Figure 1-1 Orbital Construction Demonstration Study Scope

The three fundamental phases to achieving this needed technology are shown in Figure 1-1. Initial operations will be performed directly from the Shuttle. The constraints of room power and overall flight duration of purely Shuttle sorties will eventually require augmentation from a space based platform that extends Shuttle capabilities. The initial deployment of this Shuttle tended construction platform concept was the subject of the first nine-month study effort. Ultimately, the size and complexity of the construction task will require a permanent facility for cost effective operations. The concept for a Shuttle tended platform that evolved through this study has growth capability in terms of power and support equipments to perform ambitious construction operations. These follow-on activities, along with required power and construction equipments, were the subject of the five month add on study.

1.2 STUDY PRODUCT

The key outputs of this study were a conceptual design and program plan for an Orbital Construction Demonstration Article (OCDA), that can be used for technology growth and verification, and as the construction facility for a variety of large structures (see Figure 1-2). The OCDA design includes a large work platform, a rotating manipulator boom, a 250 kw solar array and a core module of subsystems with a total mass of 37,093 kg, that can be assembled in three Shuttle flights.

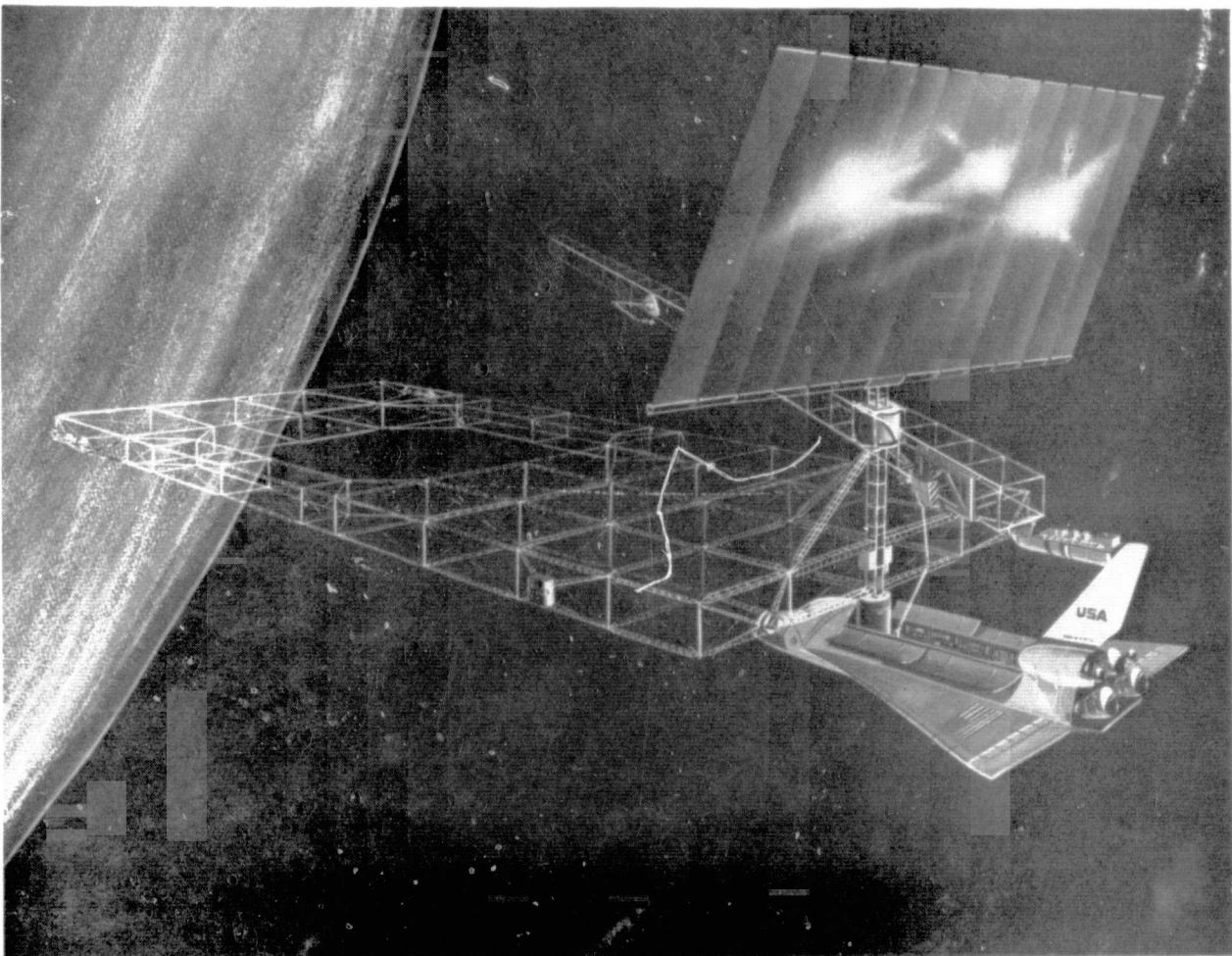


Figure 1-2 Orbital Construction Demonstration Article

The estimated cost to place the basic OCDA in orbit is \$390M. A total program including placement of the OCDA and a series of major investigations directed towards a Solar Power System would cost \$1.3 to \$1.8B. Similarly, a total program consisting of the basic OCDA, and the erection of both a major communications antenna and a large earth resource antenna would cost approximately \$1.3B.

The OCDA is a three-axis stabilized platform in low-earth orbit with many structural nodes for mounting large construction and fabrication equipments, similar to the jigs, fixtures and construction equipments used to assemble large antenna. These equipments would be used to explore methods for constructing the large structures for future space missions. Initial erection of the OCDA in a 350 km altitude orbit would provide valuable experience toward this goal. The OCDA would be supported at regular intervals by the Shuttle. Materials and consumables resupply would be performed during these Shuttle visit periods. A 250 kw solar array would provide sufficient power to support the Shuttle while attached to the OCDA and to run technology development and construction activities at the same time. Wide band communications with a Telemetry and Data Relay Satellite (TDRS) compatible high gain antenna can be used between Shuttle revisits to perform remote controlled, TV assisted construction operations.

The study of OCDA continued utility potential indicates that a Shuttle tended platform with 250 kw of power can effectively be used to construct highly beneficial antenna systems and large demonstration articles that advance Solar Power Satellite technologies. The construction of 100 m parabolic reflectors for use as a radiometer for measuring soil moisture and water salinity was found to be within the capabilities of the OCDA concept. Of perhaps even more benefit, the OCDA complement of construction equipments and power resources can be used to build a 61 m multibeam communications antenna. With 252 fixed beams for high population centers, and 16 scanning beams for rural areas, this antenna has the potential to significantly improve U.S. space-based communications systems. The OCDA, that is slightly increased in size, was found adequate to build a large 2 MW solar array which, when coupled to a transmit antenna, can demonstrate power transfer from space to ground.

Section 2

PART I (INITIAL NINE-MONTH STUDY) RESULTS

This study effort was performed in two parts. The first part was a nine-month effort that addressed the definition and utilization of a Shuttle supported construction base (Figure 2-1). The second part was a five-month effort that defined follow-on activities to a level sufficient to determine overall program costs and investigated expanded activities requirements to assess their impact upon the basic OCDA design that evolved during the initial nine-month effort.

General ground rules observed during the study were:

- The demonstration article and associated assembly procedures for initial placement and follow-on missions must be compatible with the Shuttle
- Only low earth orbit operations are considered
- Two to six Shuttle flights should be used for initial demonstration article placement
- The demonstration article should have revisit capability
- Assume an IOC of 1984 for the demonstration article
- Utilize a 1981 technology base
- Follow-on activities should be completed prior to 1987 so that data will be available for programmatic decisions on future large structures projects.

- **PART 1 – INITIAL 9 MONTH STUDY**

- **DEFINE AN ORBITAL CONSTRUCTION DEMONSTRATION PROGRAM THAT:**

- **UTILIZED SHUTTLE & STS ELEMENTS AS APPROPRIATE**
 - **DEMONSTRATES & EVALUATES ASSEMBLY TECHNIQUES FOR USE IN CONSTRUCTING LARGE OPERATIONAL SPACE STRUCTURES**

- **IDENTIFY FOLLOW-ON USES OF DEMONSTRATION ARTICLE LEFT IN ORBIT.**

- **PART 2 – ADD ON 5 MONTH STUDY**

- **AUGMENT BASIC ORBIT CONSTRUCTION DEMONSTRATION STUDY BY DEFINING FOLLOW-ON ACTIVITIES THAT WILL FURTHER ON-ORBIT CONSTRUCTION TECHNOLOGIES**

- **IDENTIFY REQUIREMENTS FOLLOW-ON ACTIVITIES PLACE ON BASELINE OCDA & RECONFIGURE TO ACCOMODATE**

- **PROVIDE PROGRAMMATIC & COST FOR INTEGRATED DEMONSTRATION PROGRAM.**

Figure 2-1 Study Objectives

The tasks performed over the initial nine-month study are outlined in Figure 2-2. The first task selected representative potential future missions and structure for the purpose of studying technology issues associated with their construction and operation. The technology issues that could not be satisfactorily addressed through a ground based program and required flight demonstration for a proof-of-concept were embodied into an Orbital Construction Demonstration Article (OCDA). Mission plans, program costs and schedules of this initial demonstration program were the main products of the effort. Supporting analysis (Task 4 in Figure 2-2) concentrated on such issues as attitude control and orbit keeping requirements associated with placing a construction article into orbit in the early to mid 1980s and investigated the demonstration article potential to perform continued useful activities.

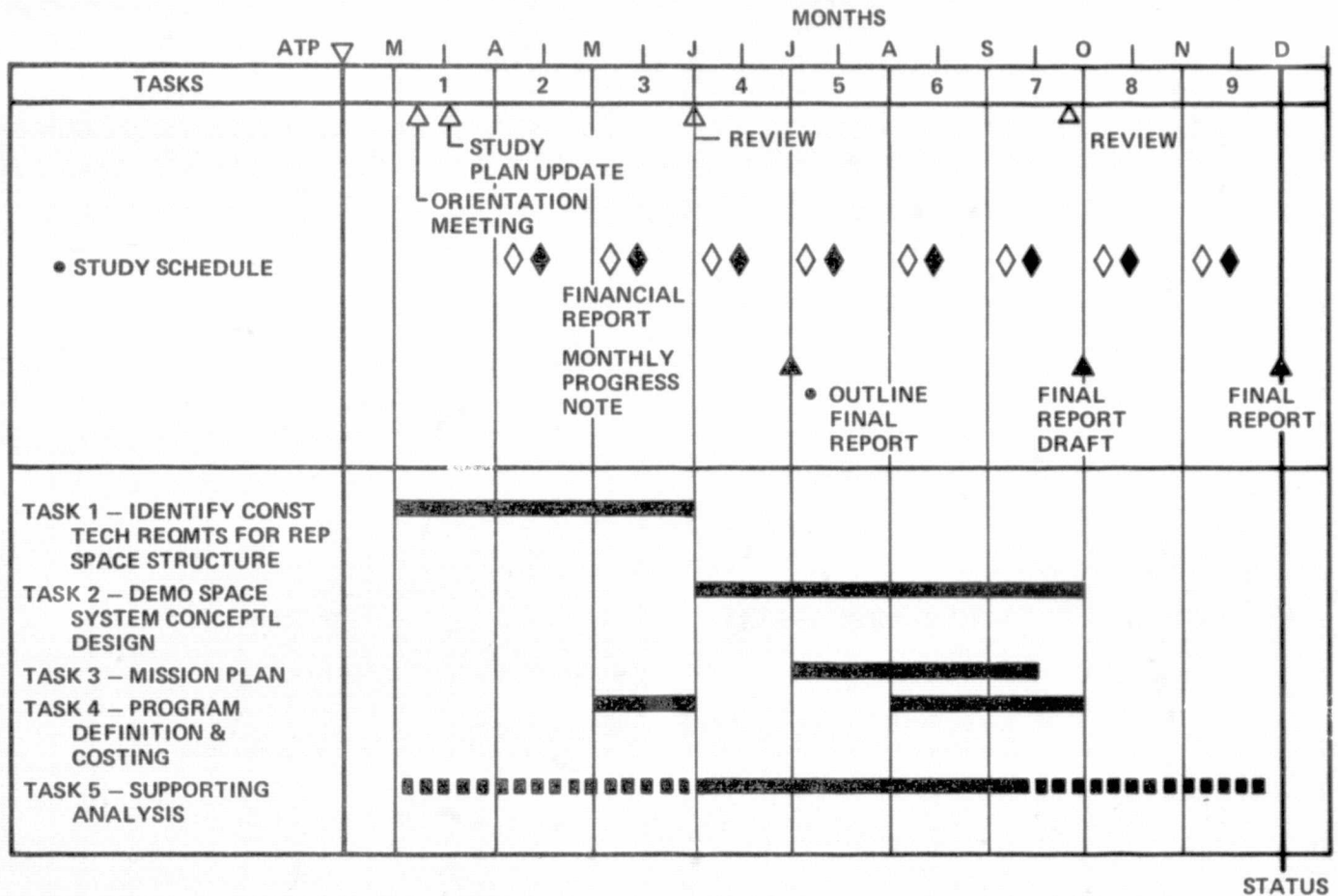


Figure 2-2 Orbital Construction Demonstration Study Schedule

2.1 FUTURE MISSION REQUIREMENTS

The Orbital Construction Demonstration Study effort was directed toward definition of the requirements that future ultra-large structures impose on near-term construction technology requirements. The approach used during the first tasks (see Figure 2-2) was to identify and describe potential large structures by reviewing future mission planning. A few representative structures were then selected for the purpose of delineating construction issues. The issues were studied to determine a near-term orbital demonstration program that would provide sufficient confidence in the state of technology to start development of these

future missions. Those issues requiring orbit demonstration were embodied in several programs of varying cost and complexity, and a program selected that met a high percentage of demonstration objectives, had reasonable cost, and offered potential for continued usage as a construction technology test facility.

In all, 40 potential structures were reviewed. This number was reduced to ten candidates, by eliminating those concepts that did not require space construction for deployment or to achieve required structural accuracy. The exception to this criteria was in the field of navigation and space colonization, where the concepts were not sufficiently defined or considered too far in the future to benefit from a near-term demonstration program. A further reduction to 5 candidate representative missions was made by eliminating system whose requirements are embodied by other systems.

The five representative structures shown in Figure 2-3 were then studied for technology requirements and categorized into 12 problem areas needing orbital construction demonstration and test. The photovoltaic Solar Array for the SPS is representative of a loose tolerance, large near-planar structure. The solar thermal version of SPS has a more complex shape in the concentrators and requires the construction of large radiators. The Microwave Power Transmission System (MPTS) is common to both the Photovoltaic and Solar Thermal SPS and is representative of moderately tight tolerance structure that must operate in a harsh thermal environment. The large parabolic radiometer reflector is representative of a complex shape requiring very tight tolerance structure while the solar mirror reflector is representative of a large planar stretched membrane.

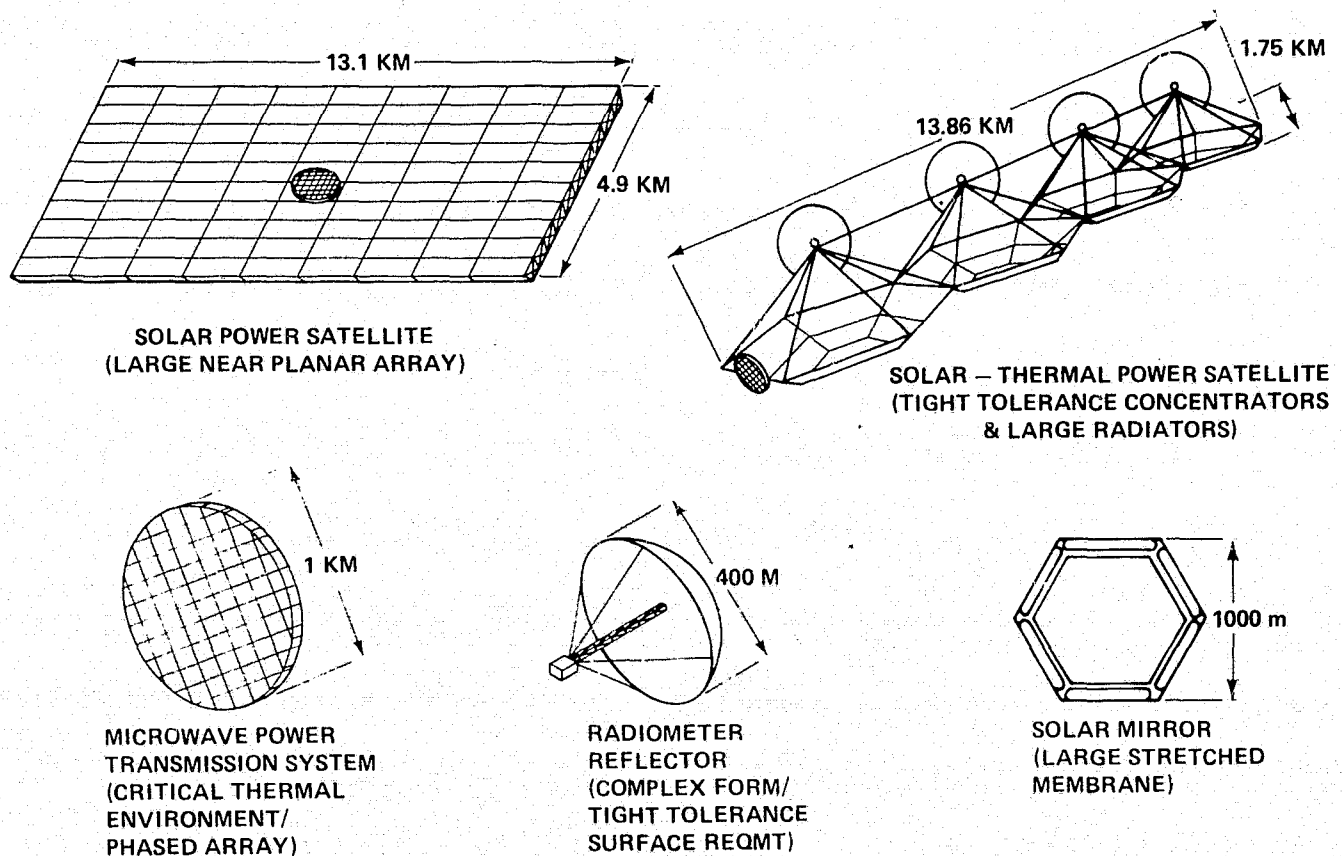


Figure 2-3 Selected Representative Structures (These Encompass the Technology Requirements of the Forty Study Missions)

2.2 NEAR-TERM DEMONSTRATION OBJECTIVES

The five representative structures were reviewed for construction requirements. Seventy-two demonstration test objectives were identified needing orbit demonstration in the 12 technology areas shown in Figure 2-4. Delineation of these objectives can be found in Volume 3 of this final report.

CATEGORIES OF OBJECTIVES WERE DEVELOPED
FROM THE FIVE REPRESENTATIVE STRUCTURES

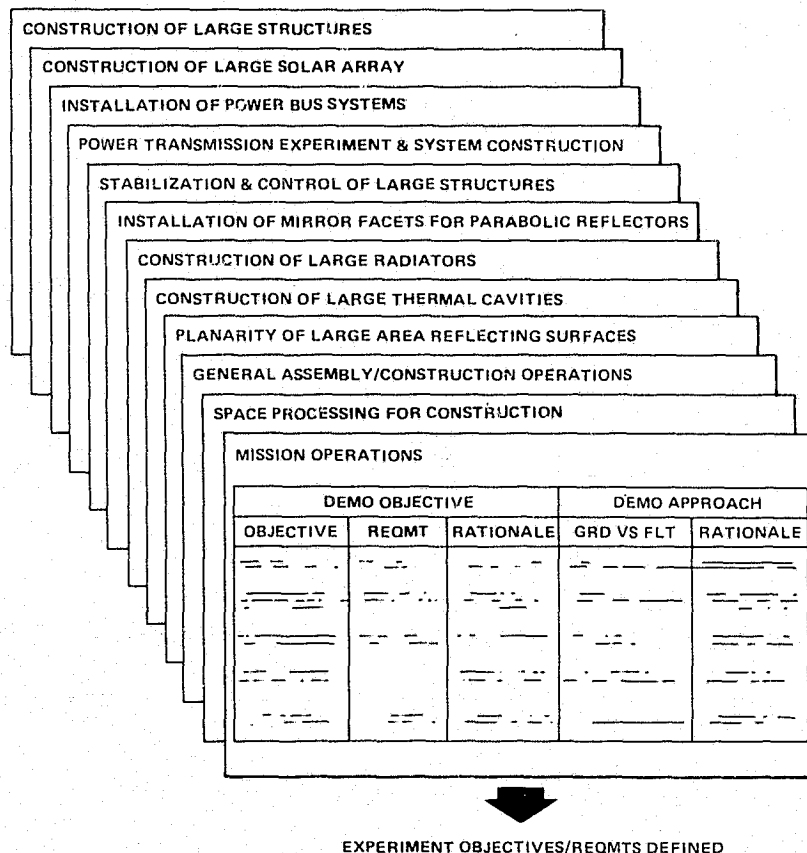


Figure 2-4 Technology Issues Requiring Orbit Demo/Test Identified in Basic Study

Each of the 72 technology issues was reviewed for the need for orbital operations and numerical priority assigned to the technology objectives as a means of later assessing the suitability of various candidate demonstration articles of meeting the more crucial issues. A typical factor considered in determining the applicability of ground demonstration is the complexity of ground handling the large size and light weight of a typical space structure. It was found that beam allowable loads would be exceeded during even the simplest of ground based logistics functions. Simulation of zero-g for as large a structural element needed in future missions was also found to be a factor supporting the need for orbital demonstration.

It was found that analysis and design methods development also need the data that space construction demonstration can provide. The analytical techniques for modelling large flexible structures can be refined as test information from an orbital demonstration becomes available.

2.3 CONSTRUCTION TECHNIQUES

The approach used to establish the demonstration objectives outlined in the previous section was to perform a functional analysis of the assembly operations for each of the five representative structures. Each assembly function was assessed for near term-demonstration requirements and compiled into a list formatted as shown in Figure 2-4.

One of the representative structures was analyzed in greater depth: the Microwave Power Transmission System (MPTS). The MPTS was selected as the study structure because the data base on this structure was the greatest at the time, based on work performed by Raytheon/Grumman on the basic antenna design, and the assembly studies performed by Martin.

Figure 2-5 presents an overview of four construction options studied for MPTS assembly. The first is the Martin "Post Walker" approach in which a set of equipments, including two manipulators, are supported on bases attached to the antenna vertical posts. The second approach uses a construction jig, which is a beam 830 m long and 25 m deep, that contains 46 sets of manipulators and construction equipments. This approach facilitates parallel production of an entire row of antenna structure. The third approach uses a long boom attached to a centrally located base. Equipments are mounted to a long boom for access to the immediate assembly location. The fourth approach utilizes a travelling fabrication unit which forms a continuous spiral, 25 m deep circumferentially, and periodically installs spacers (radial element) to build up a spoke structural arrangement.

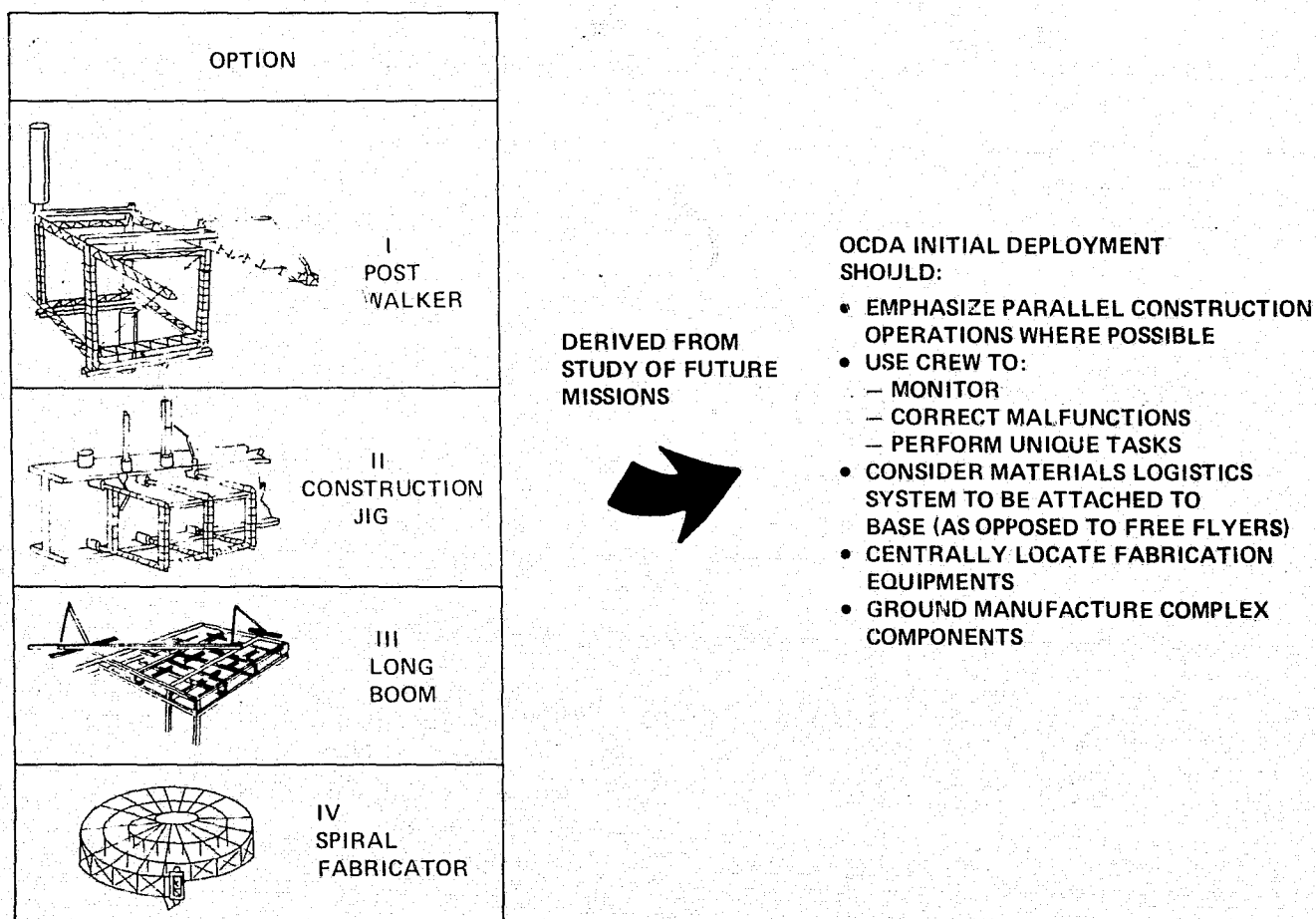


Figure 2-5 Guidelines for OCDA Assembly Demonstration

Each approach had favorable features. Options I and II demonstrate high productivity, while the centralized Options III and IV feature low capital cost in equipments. The more favorable features of each approach was compiled into a set of ground rules, or objectives, that should be utilized or demonstrated in a near-term program. These features are listed in Figure 2-5.

2.4 BUILDING BLOCK STRUCTURE AND JOINTS

In reviewing the five representative structures (Figure 2-3) groupings of structural approaches best suited to the given spacecraft were determined. These groupings are illustrated in Figure 2-6. Deployable structures were found to be best suited to structural systems in which the running length of material is less than 5000 m. Above this 5000 m running length, it was found that deployable structures would require more shuttle payload volume than a space fabrication module and associated material.

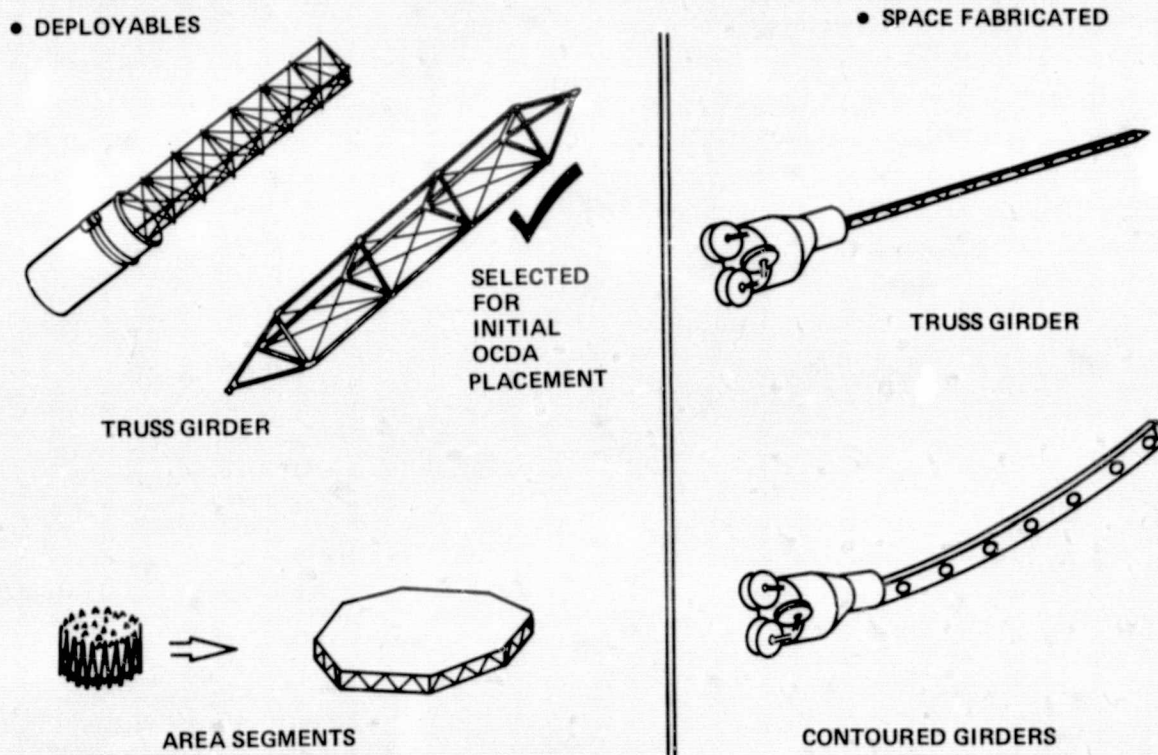


Figure 2-6 Building Block Structure

Two types of deployables should be considered in a demonstration program: Truss girders which, after deployment, can be built up into platforms or other unique structures such as solar thermal concentrators; and deployment of area segments which are particularly well suited for contoured antennas or flat platforms.

Uses for two types of space fabrication building blocks were also identified. Straight truss girder members were found to be ideal for very large repetitive structures like the Photovoltaic SPS. Contoured girders were found to be potentially applicable for tight tolerance structures, such as large parabolic antennas where it may be desirable to reduce the number of joints in the structure to achieve high accuracy.

The deployable truss girder was selected as the building block for the OCDA primarily because the technology is most advanced. Demonstration of the other types of building block structure were assigned to OCDA follow-on missions.

Using a typical triangular truss girder beam, two basic joining methods (lap and centroidal joints) for assembling a cap member and two posts were evaluated (Figure 2-7). The criteria used in the evaluation included methods of attachment (weld, bond, or mechanical); ease of alignment and possible realignment; and joint integrity and producibility. The analyses of these joining systems tended to favor the centroidal joint using mechanical fasteners. Further in depth study of this key large structures area is needed before a final selection is made.

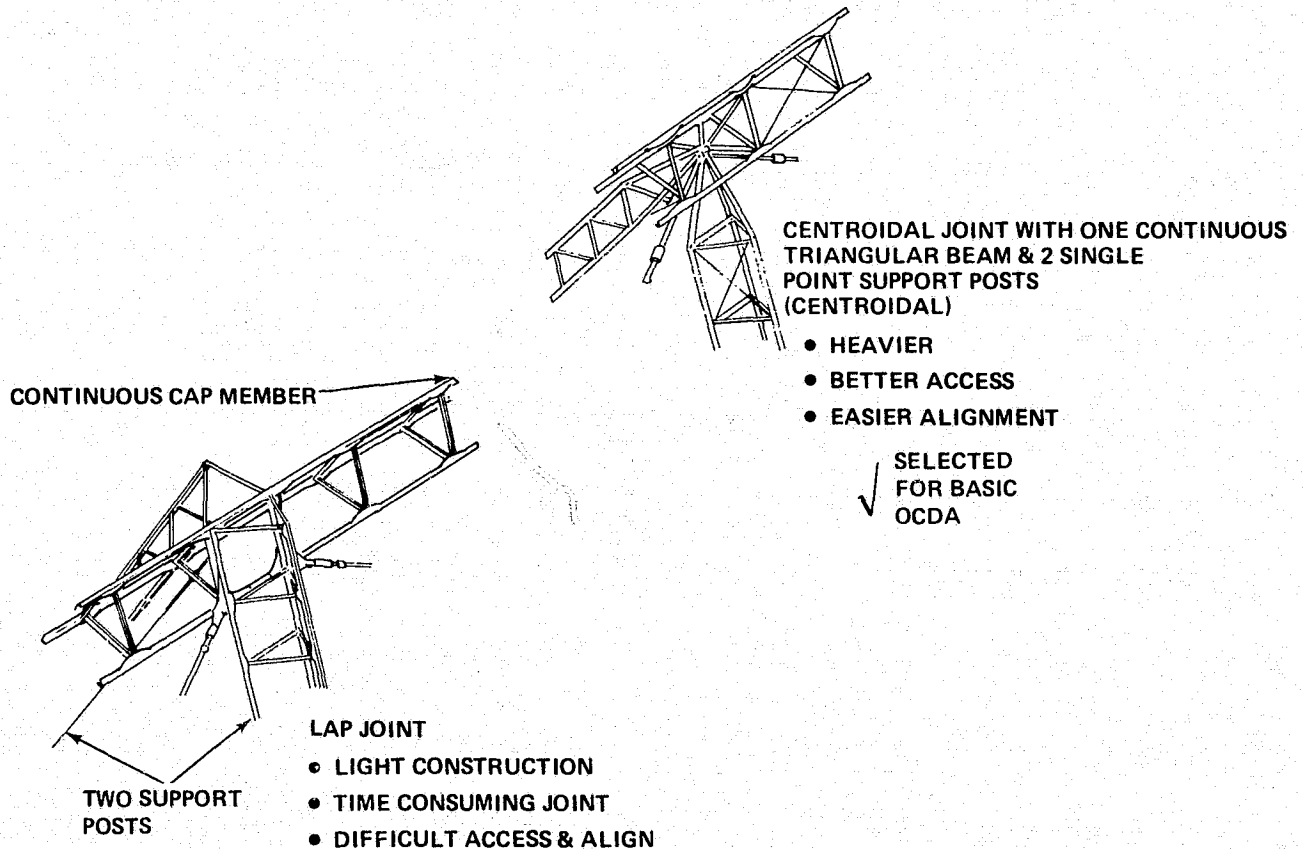


Figure 2-7 Selected Joint and Fastener Techniques

2.5 APPROACHES TO THE DEMONSTRATION PROGRAM

The demonstration objectives identified in the early phase of the study were used to formulate the two basic OCDA programs outlined in Figure 2-8. The first program starts with a construction base with a sufficiently large power source to perform follow-on activities simulating the space fabrication techniques required for future system applications. The second program starts with a large 1 MW power source to pave the way for a proof-of-concept for space based solar power generation and transmission.

2.5.1 Program I – General Purpose Construction Base – Figure 1-2 is a conceptual drawing of a stand-alone multi-purpose demonstration article that starts Program I. The configuration contains twenty

8 m X 8 m bays to form a platform or factory floor. Each bay contains attach points compatible with a shuttle pallet of equipments. A large 24 m X 32 m open area is provided for follow-on operations to demonstrate procedures for mounting solar blankets, thin film mirror surfaces of wire mesh and receiving rectenna mesh. A core module, mounted to the end of the platform, contains the articles subsystems and Shuttle docking interface. A 108 m rotating boom outfitted with a Shuttle manipulator arm transports equipments and materials from the Orbiter payload bay to the immediate work area on the platform. A 250 kW solar array is the power source for conducting construction and testing in the construction field and experiments in the SPS microwave testing field. The Solar array is configured using 13 modified SEPS blankets. Of the 250 kw, 34 kW is required for OCDA housekeeping and 36 kW is required for Shuttle support.

PROGRAM	OPTION	DESCRIPTION
I	1	BASIC CONSTRUCTION BASE WITH 250 KW SOLAR ARRAY
	2	OPTION 1 PLUS BUILDING OF 100 M RADIOMETER
II	3	BASIC CONSTRUCTION BASE WITH 1 MW SOLAR ARRAY
	4	OPTION 3 PLUS BUILDING OF TRANSMISSION ANTENNA FOR SPS PROOF OF CONCEPT

Figure 2-8 Program Options to Accommodate 72 Objectives

A typical follow-on mission that advances the technology base for Solar Power Satellites is the fabrication of a 20 m deep beam using the equipments similar to those shown in Figure 2-9. Four 1 m beam fabrication modules are synchronized to produce the cap members and battens for a 433 m long beam that is representative of the building block element for the ultimate SPS. Key technologies such as the assessment of productivity, beam alignment and joint integrity can be addressed.

Another key technology related to SPS can be handled by taking advantage of the large OCDA solar array. The phase control of the Microwave Power Transmission System (MPTS) can be tested using a configuration similar to that shown in Figure 2-10. Twenty 5 kW amplitrans can be interfaced to a 105 m long linear waveguide mounted to the OCDA rotating boom. Control electronics that perform the phase control function are then used to focus the 20 subarrays that simulate the 10 db taper power density profile of the ultimate MPTS antenna.

Evaluation of the Option 1 growth potential was made by determining cost and operations requirements for constructing a 100 m diameter parabolic radiometer, which is shown conceptually in Figure 2-11. The radiometer utilizes multiple radial elements and rings to achieve a surface tolerance of from $\lambda/10$ to $\lambda/50$. The antenna is constructed by placing a hub at the edge of the OCDA platform. The antenna radials

are space fabricated and then placed into the hub. The hub is then rotated 3.8 deg and the next radial inserted. Circumferentials are then inserted between radials and a rf mesh gore installed to the radials. This procedure is repeated until the entire antenna is constructed.

2.5.2 Program II – SPS Demonstration/Construction Base – A second approach to the OCDA program, shown in Figure 2-11, is focused on providing an SPS proof-of-concept pilot plant that can transmit demonstrable power to the ground from low earth orbit (LEO). This program starts with the same construction platform and rotating boom as Program 1, but replaces the 250 kW solar array with a 1 MW advanced technology array that operates at a concentration ratio of 2 (Option 3 in Figure 2-8). Option 4 (Figure 2-12) is the representative growth path that utilizes the construction facility to assemble a transmit antenna with a 72 m aperture dimension. With this combined 1 MW solar array (Option 3) and 72 m aperture transmit antenna (Option 4) 10 kW of power output can be developed for a brief span of time at a ground receiving antenna.

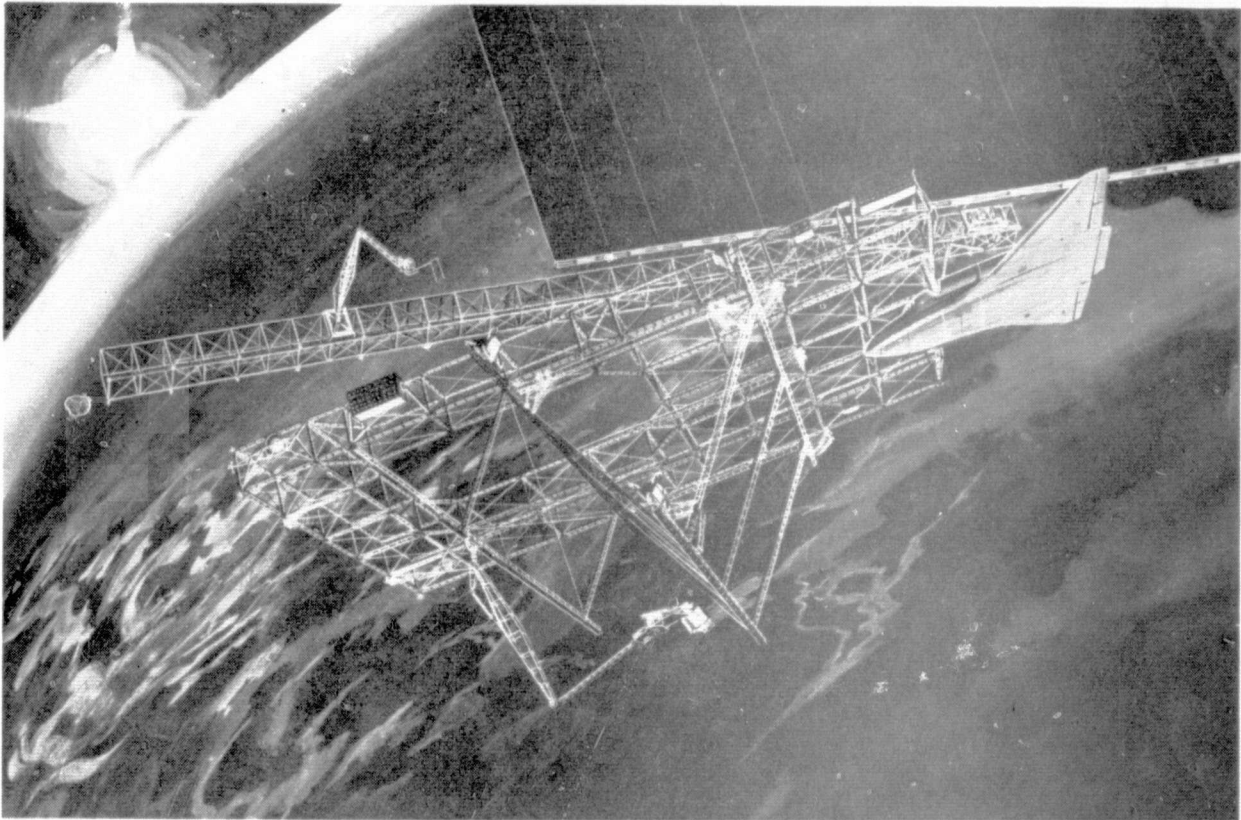
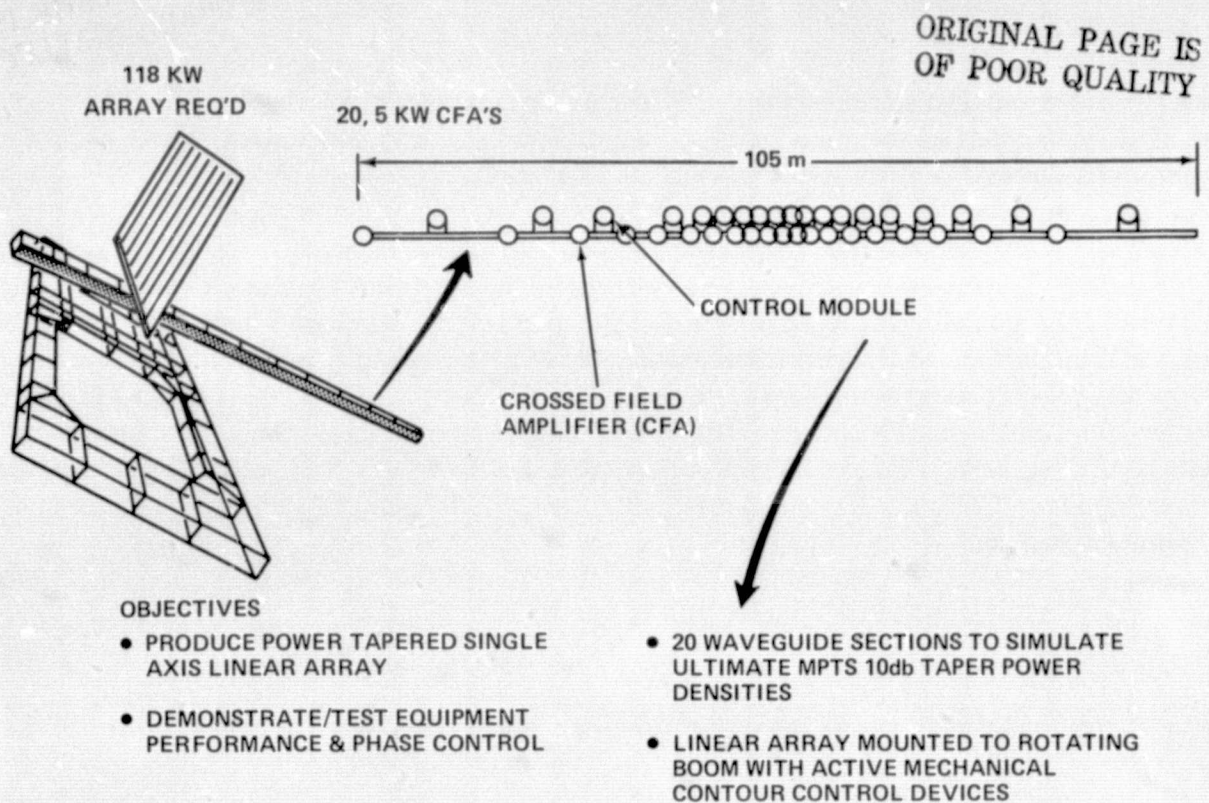


Figure 2-9 Orbital Construction Demonstration Article With Space Fabrication Equipments Attached for 20-m Deep Beam Construction



REQ'MT SOURCE: SPACE STATION SYSTEMS ANALYSIS STUDY (NAS 8-31993)

Figure 2-10 Typical Follow-On Experiment (Microwave Linear Array)

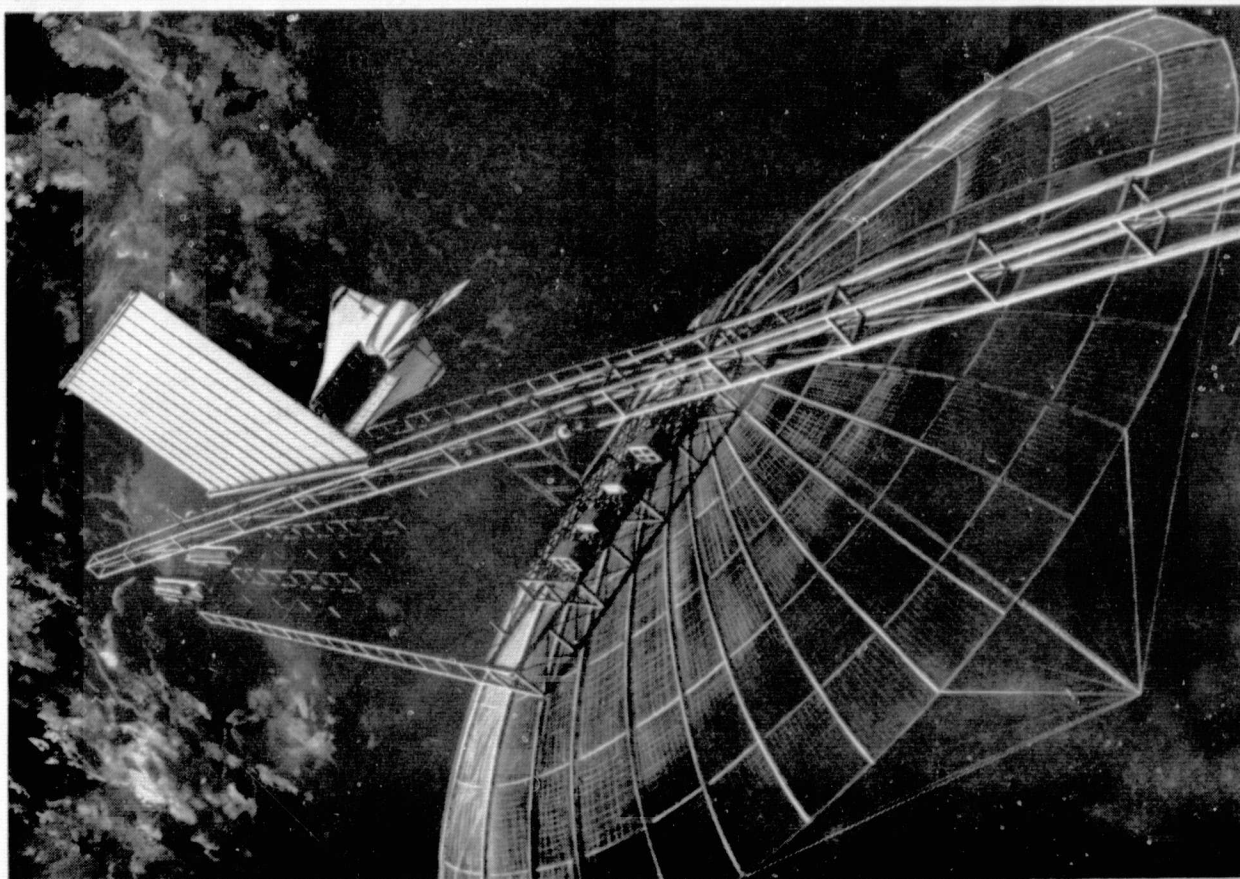


Figure 2-11 Typical Program 1 Usage—Radiometer Construction—(Option 2)

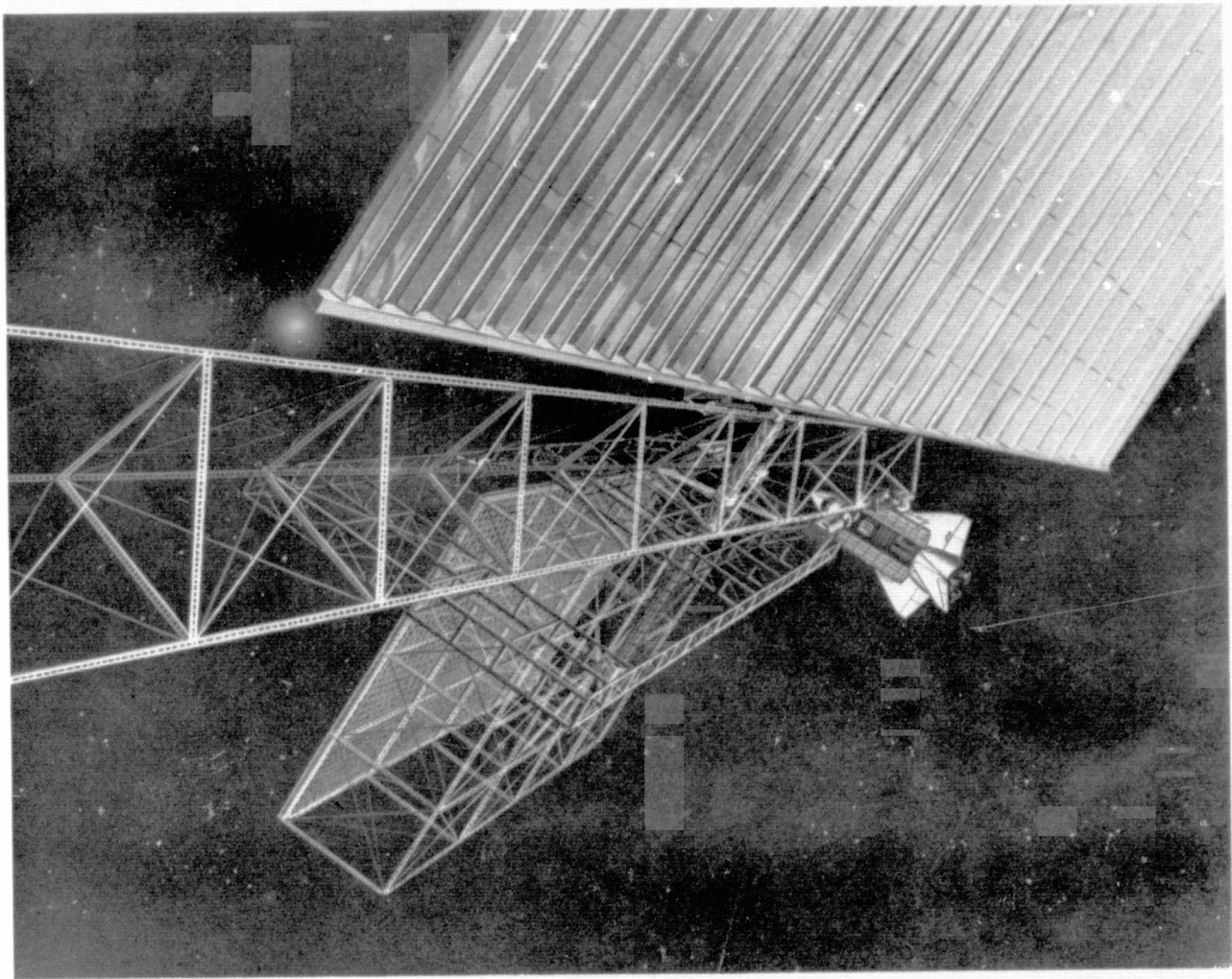


Figure 2-12 Program 2—Typical Operational Usage (Option 4)

2.6 CONCEPT SELECTION

The two basic programs discussed earlier were evaluated and compared using the following criteria:

- Mission Suitability (% Objectives Met)
- Cost/Numbers of Flights for Deployment
- Continuing Utility Potential
- State-of-the-Art (Risk)

A figure of merit mission suitability parameter was established using the demonstration objectives defined in Section 2.2. Option 4 was ranked the highest while Option 1 was ranked the lowest. However, the difference between options in terms of mission suitability was not so great as to single out any one option as a clear leader. More specific definition of the objective met during initial deployment can be found in Section 2.8.

An estimated cost comparison of the four OCDA options is shown in Figure 2-13. Cost ranges are given for DDT&E, first unit and the number of Shuttle flights required to deploy and construct the article. The ground rules used in establishing these estimates were:

- Cost in 1977 constant dollars
- Cost data excludes crew equipments and orbital construction facilities/equipments
- The core vehicle will consist of 75% off-the-shelf NASA standardized spacecraft subsystem modules
- Solar array development cost are the same as that for the SEPS program.

The initial cost estimates, assuming \$19.5 million per Shuttle flight, were as follows:

- Program I
 - Option 1: \$199 to \$362 million
 - Option 2: \$434 to \$698 million
- Program 2
 - Option 3: \$379 to 622 million
 - Option 4: \$583 to 939 million.

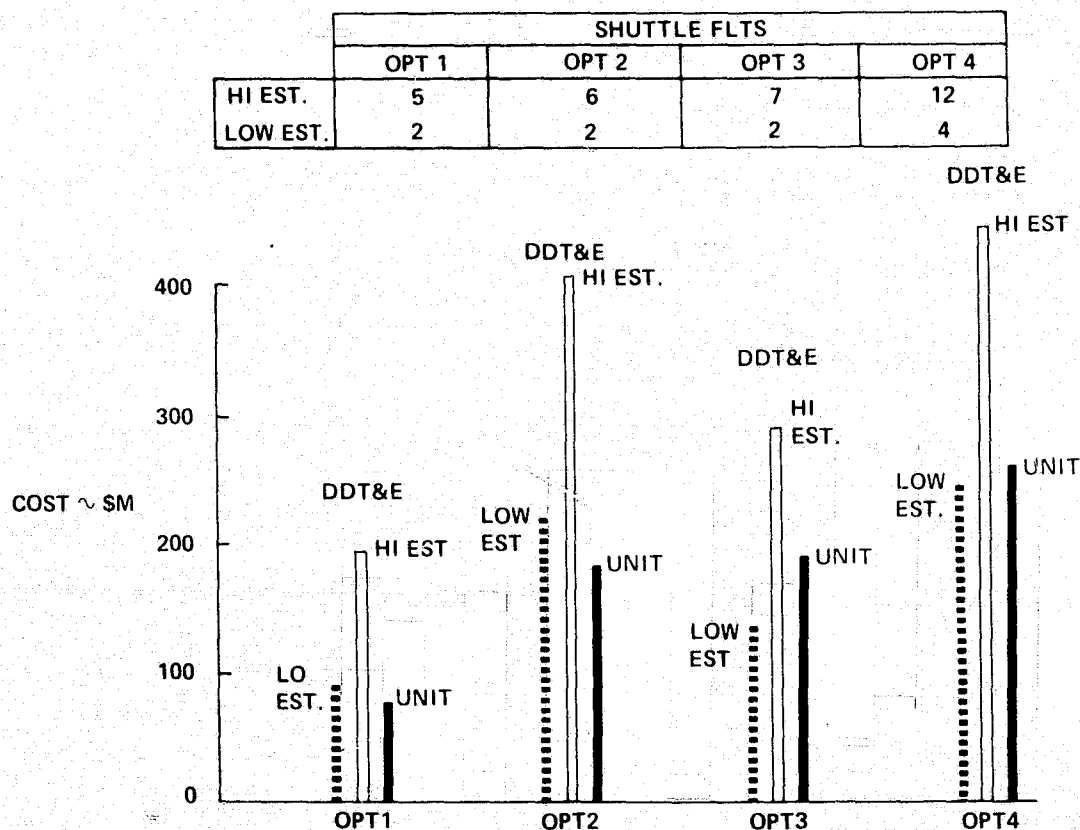


Figure 2-13 Concept Cost Comparison

Option 1 (Figure 2-14) was selected for concept definition. The 250 kW array was judged at the time to be adequate to meet near-term construction demonstration objectives with Shuttle revisits to the OCDA. Costs for Option 1 were considered modest for a program of this type. The low risk of equipment development was also a key factor in the selection of Option 1. The major risk factor for Option 1 pertained to the actual assembly operations and not to the hardware.

The growth paths for Option 1 were the central task of Part 2 of the study and is discussed in more detail in Section 3.0.

BASELINE SELECTED ✓

	PROGRAM 1		PROGRAM 2	
CRITERIA	OPT 1	OPT 2	OPT 3	OPT 4
MISSION SUITABILITY (RANK)	4th	3rd	2nd	1st
COST				
DDT & E (\$M)	90 TO 195	205 TO 400	150 TO 295	250 TO 450
UNIT (\$M)	70	180	195	260
FLTS	2 TO 5	2 TO 6	2 TO 7	4 TO 12
CONTINUING UTILITY POTENTIAL	GOOD	VERY GOOD	EXCEL.	EXCEL.
STATE-OF-ART. (RISK)	LOW	HIGH	MODERATE	HIGH

- 
- 250KW ARRAY IS SUFFICIENT TO MEET NEAR TERM MODEST CONSTRUCTION DEMO OBJECTIVES
 - COST MORE IN LINE WITH BUDGETS
 - LOW RISK IN LINE WITH IOC.

Figure 2-14 Concept Comparison

2.7 BASELINE OCDA DEFINITION

The OCDA definition discussed in this section is the product of Part I of the study. A summary of the impacts that the follow-on activities have on the basic OCDA design will be discussed in Section 4, Design Requirements.

2.7.1 Configuration

The OCDA, shown in Figure 2-15, has four major elements: core module/mast, platform, rotating boom and solar array.

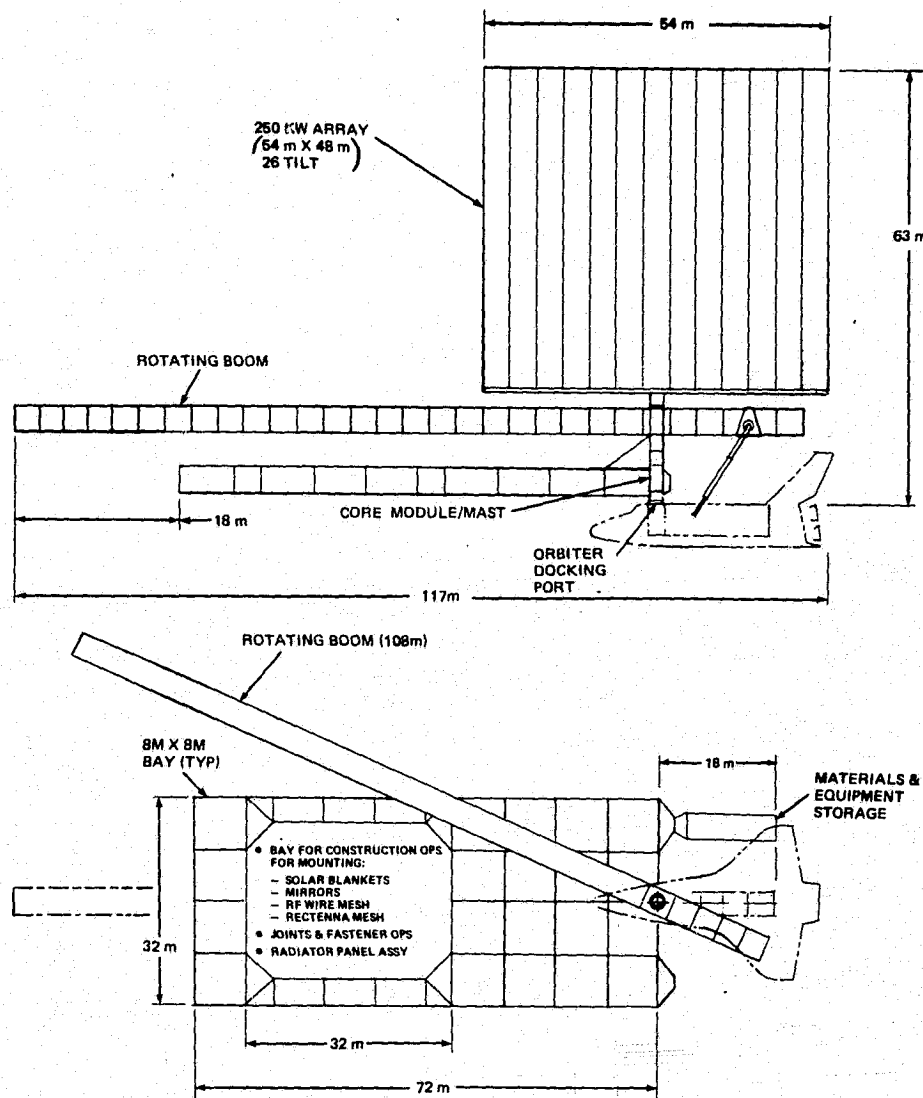


Figure 2-15 General Purpose Demonstration/Test Facility for Construction Technology

The core module/mast contains the article's subsystems, including attitude control, power regulation and control, and communications and data handling. A shuttle compatible docking mechanism is included, as well as the rotary joint interface with the solar array and rotating boom. The work platform is configured with twenty 8 m square by 4 m deep rectangular prisms or bays. Each bay provides nodal pickup points to support fixtures compatible with a Shuttle pallet of experiments and equipments. A large 24 m x 32 m open area is provided for demonstrating procedures for mounting solar blankets, thin film mirror surfaces, wire mesh and other broad area component installations.

A 108 m rotating boom outfitted with Shuttle manipulators and an equipment traveller (materials logistics module) is used to transport equipments and materials to the assigned work platform station. The boom is instrumental in the initial construction of the OCDA and is used in follow-on activities for the construction of hardware outside the confines of the platform itself.

The 250 kW solar array is composed of 13 modified Solar Electric Propulsion Stage (SEPS) wrap-around silicon cell deployable blankets. This power level was selected to provide 19 kW average power (38.43 kW array size) for OCDA housekeeping, 20 kW average power (40.36 kW array size) to support the Shuttle and 85 kW average power (171 kW array size) for follow-on mission-related activities.

The OCDA mass is 37,093 kg including a six-month supply of consumables and a 20% contingency (Figure 2-16). The electrical power system, which utilizes a NASA multi-mission spacecraft EPS module enhanced by additional batteries and regulators, is the heaviest element of the core section, primarily due to wire weight needed to route power from the solar array to the rotating boom and platform. The platform (8327 kg) is the heaviest system element with the structure and power distribution system conductors making up 78% of the mass. The rotating boom mass (6869 kg) is influenced most by the conductors (4394 kg) needed to perform follow-on mission experiments in the field of microwave testing. The solar array's 13 SEP solar blankets, support structure, routing wire, etc., constitutes 19% of the spacecraft dry mass.

		LBM	Kg
• CORE MODULE/MAST	(7669)	(3477)	
– STRUCTURE		316	143
– DOCKING MODULE (PASSIVE)		320	145
– COMM & DATA HANDLING		270	122
– ELECT POWER		3519 ①	1596
– ACS MODULE & REACTION WHEELS		1144	519
– SOLAR ARRAY/ROTATING BOOM DRIVE UNIT		2100	952
• PLATFORM	(18,361)	(8327)	
– STRUCTURE		7421	3365
– PWR DISTRIBUTION		7194 ②	3263
– PROPULSION ORBIT KEEP MODULE (2)		436	198
– ORBIT KEEP MODULE SUPT STRUCT		265	120
– LOGISTIC DOCKING PORT (2)		640	290
– PROPULSION, ATTITUDE CONTROL			
– MODULE (2)		1907	865
– ATTITUDE CONT MODULE SUPT STRUCT		375	170
– COMM-ANTENNA'S (KU-BAND & S-BAND)		123	56
• ROTATING BOOM	(15146)	(6869)	
– STRUCTURE		4349	1972
– MANIPULATION & CARRIAGE		966	438
– TRAVELLER		143	65
– POWER DISTRIBUTION		9688	4394
• SOLAR ARRAY	(12,304)	(5458)	
– STRUCTURE		593	269
– SOLAR BLANKET & DEPLOY MECH.		9634	4369
– POWER DISTRIBUTION		1746	792
– ACS, SUN SENSORS (2)		28	13
– TILT MECHANISM		33	15
TOTAL		53210	24131
20% CONTINGENCY		10642	4827
		63852	28958
CONSUMABLES		17938 ③	8135
		81790	37093

① INCLUDES 583 lbM POWER MODULE
 ② INCLUDES 1818 lbM ORBIT KEEP BATTERIES & 452 lbM POWER REGULATION
 ③ INCLUDES 6 MONTH SUPPLY OF ACS HYDRAZINE (16,700 lbM)
 6 MONTH SUPPLY OF ACS He (86 lbM)
 6 MONTH SUPPLY OF ORB KEEP ARGON (1152 lbM)

Figure 2-16 Mass Summary

The OCDA is constructed from an Orbiter base in three flights (Figure 2-17). The first flight deploys the core module as a single unit and adds one section of the solar array and the trailing section of the rotating boom. The second flight is used to construct the inner 32 m x 32 m area of platform, the remainder of the 108 m long boom and the remainder of the solar array. The third flight is used to complete the platform structure and to install the power distribution system.

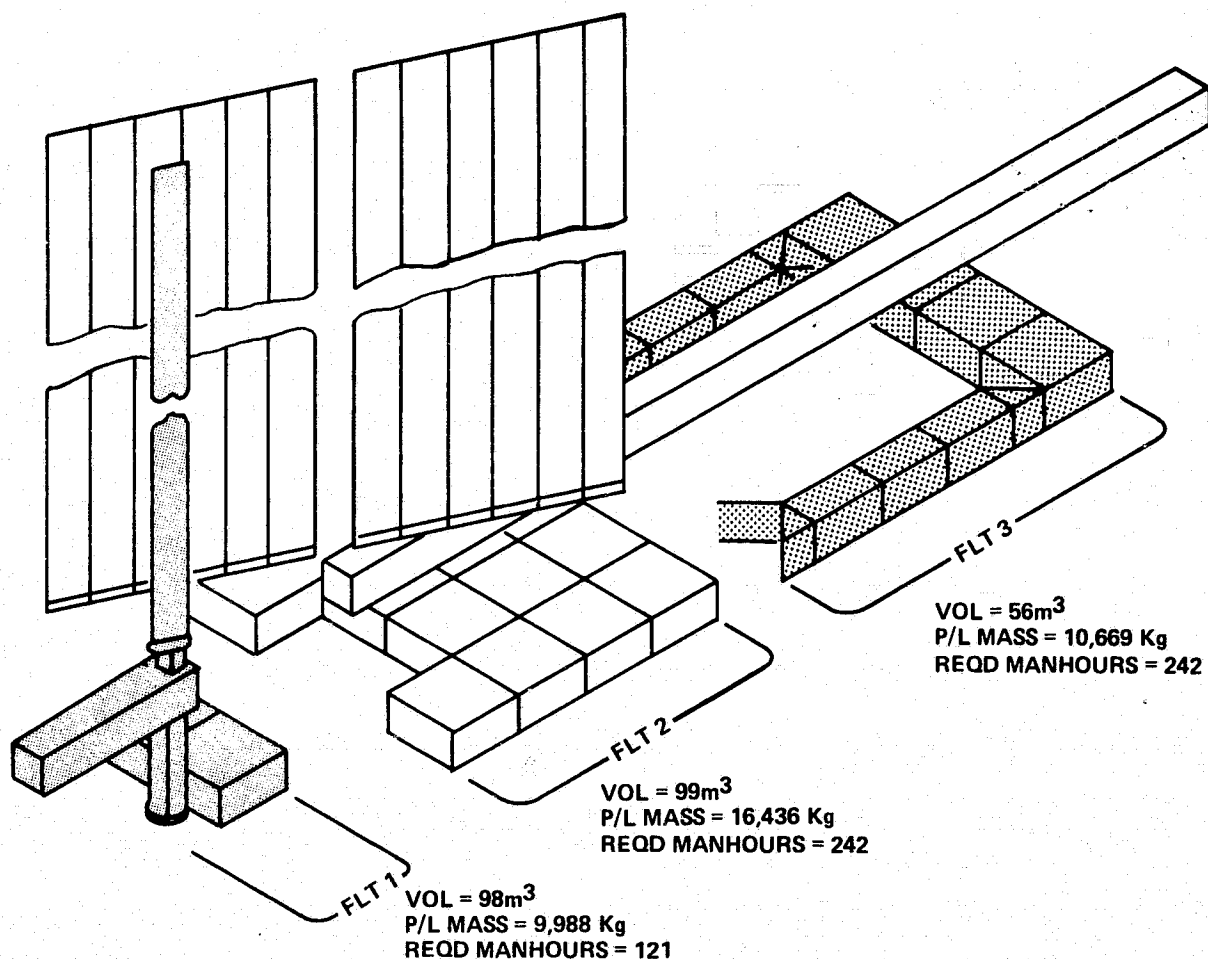


Figure 2-17 Selected OCDA Assembly Technique—Three Shuttle Flights

2.7.2 Core Module/Mast

The central mast shown in Figure 2-18 is the first element of the OCDA to be deployed and consists of 1.4-m square open truss structure, 10.5 m long, which is structurally connected to the platform at three levels. The Shuttle Docking Module (Passive) is mounted on the end of the mast. A 2 m x 2 m opening on the face of the mast provides ingress/egress on the orbiter docking module. The ACS and C&DH modules are mounted on the side of the mast, close to the docking ring while the EPS module is mounted on the opposite side. Three reaction wheels (ACS), roll, pitch, and yaw are mounted midway between the platform and boom.

The boom/solar array drive unit is mounted on the end of the square mast. A deployable 3.5 m length of the RMS rails/boom and support structure are attached to the boom drive. The docking ring, mast and drive unit with the deployable RMS/boom structure make up 15 m of the core module which is preassembled and removed from the orbiter payload bay as one unit. A single solar array module and its support structure are attached to the drive unit and, together with the 15 m length of core, complete the core module.

The rotation boom/solar drive contains two separate drive units in one package: a solar array drive and a drive unit to rotate the OCDA boom. Both drive mechanisms apply torques against the OCDA mast structure and both driving functions are completely independent of each other.

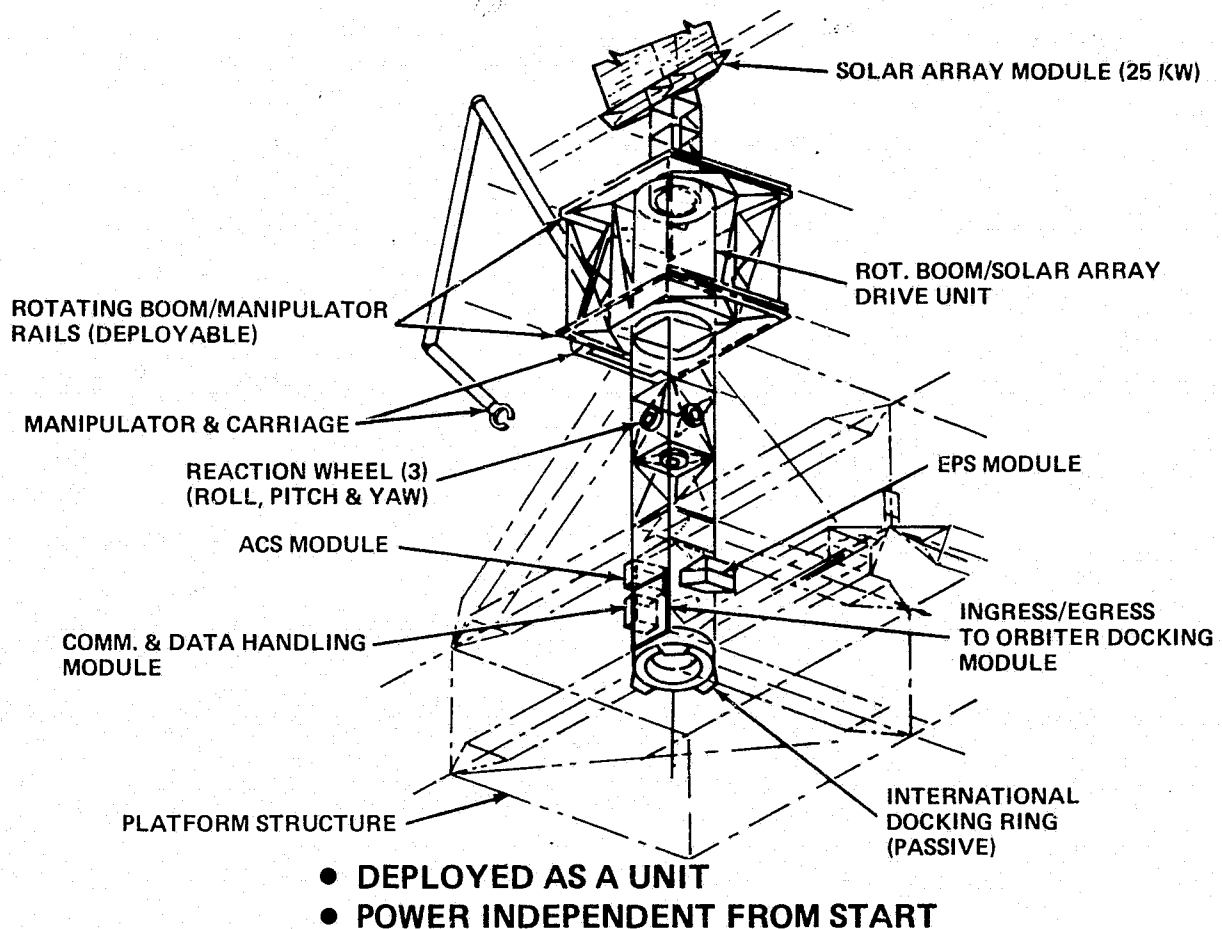


Figure 2-18 OCDA Core Module/Mast Configuration Detail Design

2.7.3 Rotating Boom

The next major element to be assembled (Flight 2) is the rotating boom. The components of the rotating boom are the 108-m long x 4-m square structure that supports a manipulator carriage and materials traveler. These elements are conceptually shown in Figure 2-19.

The manipulator used on the OCDA is a standard Shuttle RMS. The manipulator is attached to a carriage mounted on the rails and can move along the boom. The manipulator carriage is unpowered and is moved from one place to another by the traveler. When the manipulator carriage is at the desired location, it is locked to the rail and uncoupled from the traveler. An electrical umbilical runs from the umbilical reel down the boom to the docking port on the core module. Operation of the manipulator is accomplished from the RMS operator station in the shuttle, using lights and TV cameras on the manipulator to provide visibility. The umbilical is hard wired to the manipulator.

The traveler is an electrically powered cart that rides the boom to relocate the manipulator carriage and transport men and materials to the work site. The traveler draws power from a power pickup rail mounted on the boom.

The boom is built up in 8 m and 16 m long sections of deployable structure. Each structural section contains all the wiring and rail elements needed to support the manipulator and traveler.

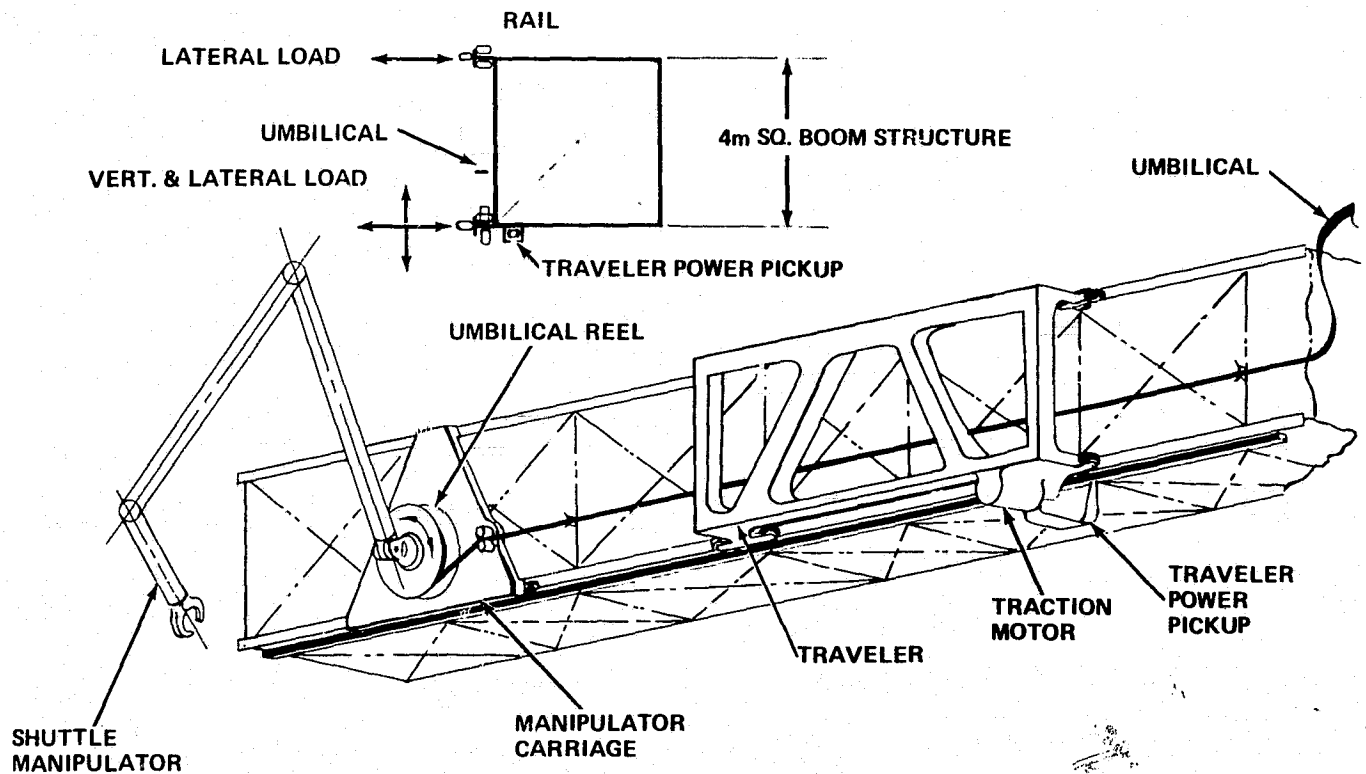


Figure 2-19 OCDA Rotary Beam/Manipulator and Traveler Design

2.7.4 Solar Array

The OCDA solar array shown in Figure 2-20 is assembled on Flight 2 and mounted on the "upper" end of the core module/mast. The array is intended to serve in two configurations; a modest sized array to provide housekeeping power for the platform functions, shuttle support and moderate experiment load, as well as a very large array (250 kW) for a specific experiment requiring high power. The array design is modularized to facilitate assembly and to match the deployed array with the power requirements.

The basic component of the modules is an expanded capacity SEPS solar array. The capacity is increased by extending the deployed length by 50%. The array modules (each contain their own extension mechanisms) are deployed side by side to achieve the required power level (250 kW maximum). The entire array consists of a central module and 12 add on units. The overall size of the full array is 48 m x 54 m. Each array section provides 19.2 kW of power.

The solar array is assembled by the manipulator on the rotating boom using a procedure similar to that shown in Figure 2-21. The manipulator operations are guided by an EVA crewman with MMU. Probe/drogue fittings at each corner of the triangular support structure are engaged and locked, interfacing the power busses and avionics wiring.

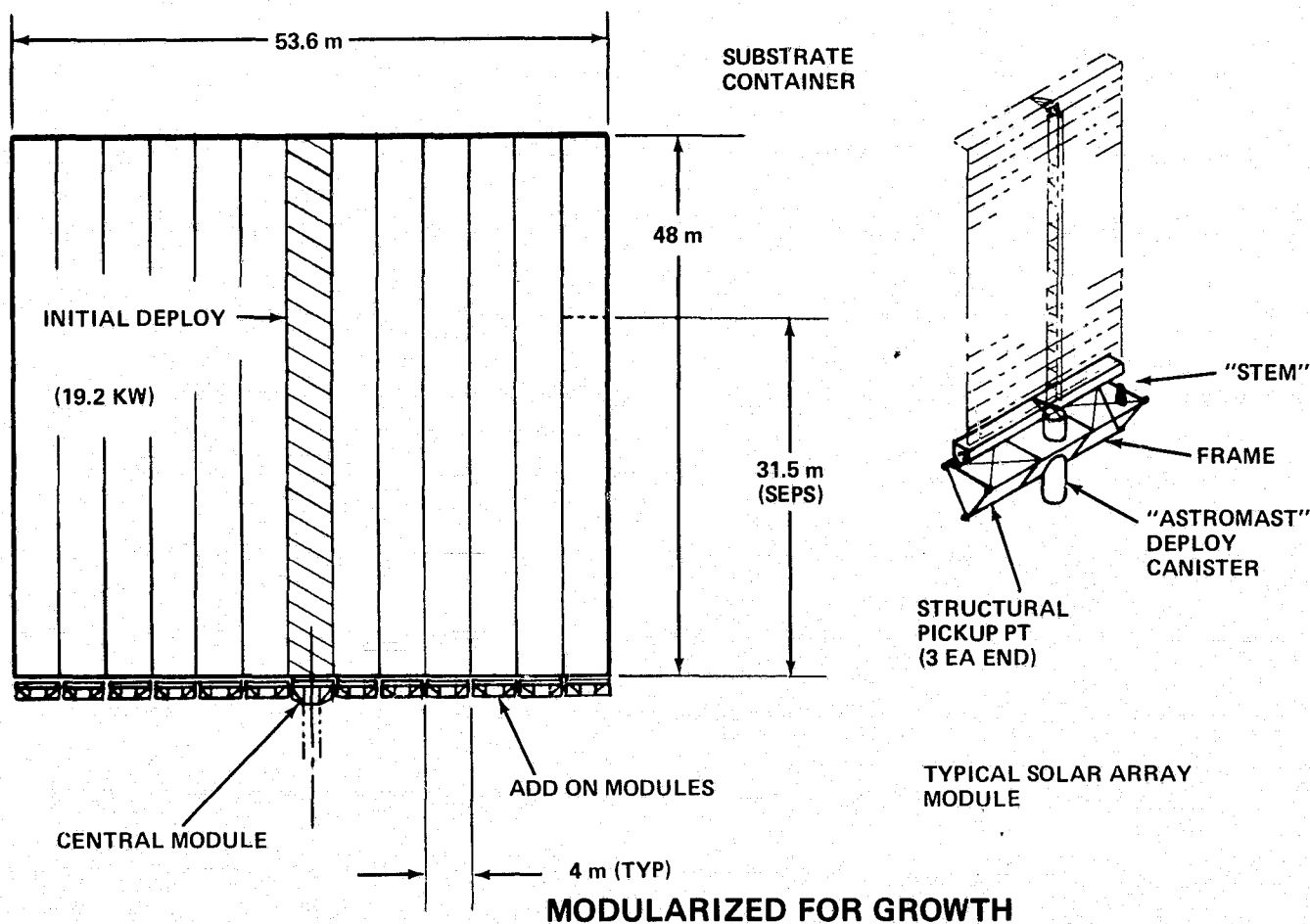


Figure 2-20 OCDA-Solar Array (250 kW)—Detail Design

2.7.5 Platform

The platform utilizes deployable triangular section members with centroidal end fittings (nodals) configured to form rectangular prisms. The 8-m length of the members was chosen to provide efficient stowage within the Shuttle cargo bay. The use of centroidal fittings allows determinate load paths and provides tiedown points on the surface of the platform for mounting equipments. Tubular posts with built-in toe holes or hard points for the construction crew are used between the surface of the platform. Diagonal bracing is used to rigidize the bays and provide shear and torsional stiffness to the structure. A large open bay is provided with surrounding structure arranged to provide a continuous edge upon which solar blanket and reflector attachment bungees can be fastened. Trusses stabilize the cargo module docking ring and carry the loads into the edge of the platform structure.

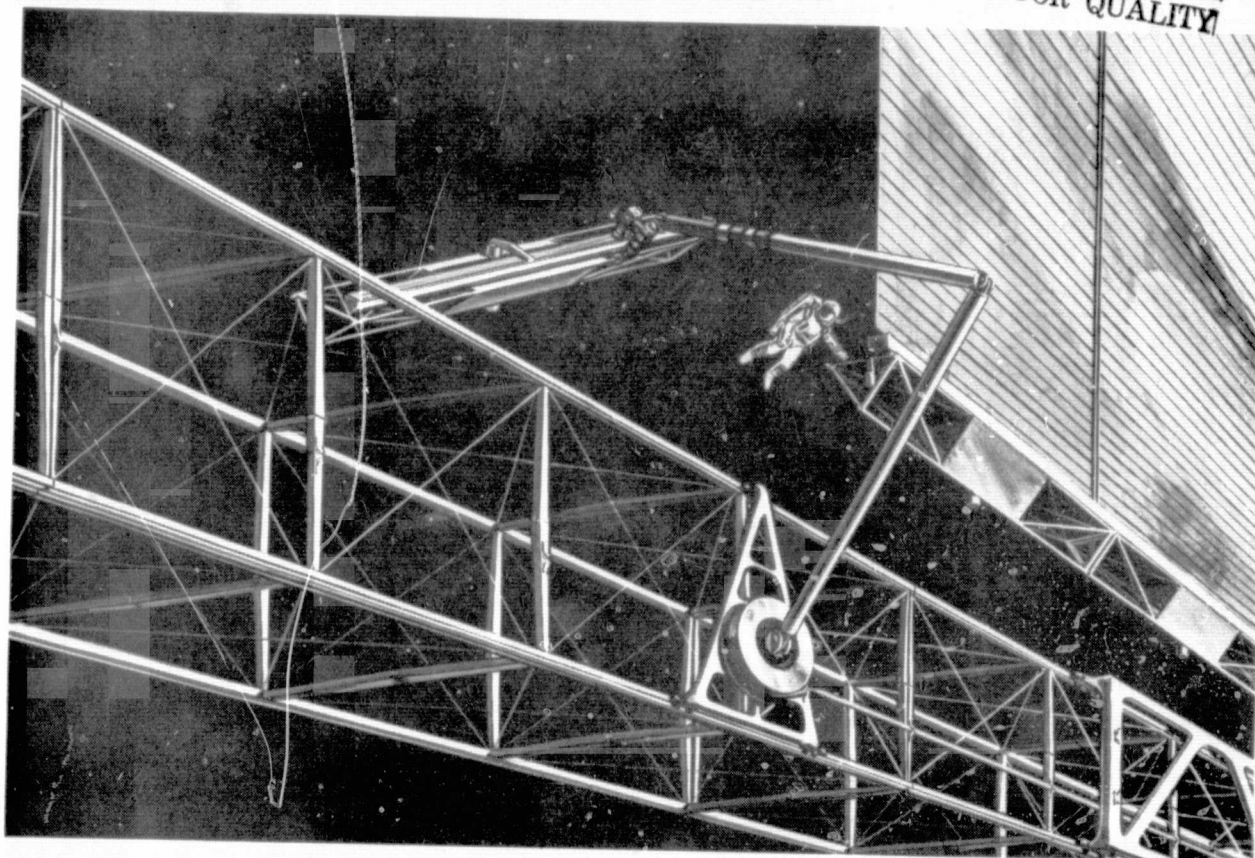


Figure 2-21 Solar Array Assembly from Rotating Boom

The platform structure is built up from the deployable elements shown in Figure 2-22. It has a 1-m deep triangular section and is 8 m in length. Because structures this size fit easily within the shuttle cargo bay, continuous longerons are used to eliminate the structural deadband that results from joint clearances. The structure is compacted by folding the battens of each bay, shrinking the cross section. The folded batten is entrapped between longerons which provide support during liftoff. On deployment, the batten unfolds and is locked in the extended position by an overcenter lock. Cross bracing is used to stabilize each bay. A set of folding links takes up the cable slack when the structure is retracted. This deployment approach can also be used for structures to be fastened end-to-end to make continuous members.

The retracted structure has a cross section area of 0.021 sq m and a volume of 0.335 cu m. A dedicated shuttle flight could deliver 8944 m of structure (approximately 1000 m are required for the OCDA platform structure). The structure is held in the retracted position by pins that hold the longerons together. Deployment is initiated by pulling the lock pins with a lanyard. The structure is deployed by the energy stored in the batten lock torsion springs.

To minimize platform installation time and insure dimensional repeatability, a subassembly fixture is utilized in the orbiter payload bay. The fixture, shown in Figure 2-23, uses adapters that pick up the orbiter payload bay longeron attach points. The fixture is constructed of composites to minimize dimensional changes and locates four nodal fittings for a 8 m x 8 m x 4 m platform element. Five of the six element faces are assembled using deployable 8 m beams, 4 m tubular posts, and tension rods. The aft face, including two 4 m posts, is assembled and locked in position. The side beams, side tension rods and

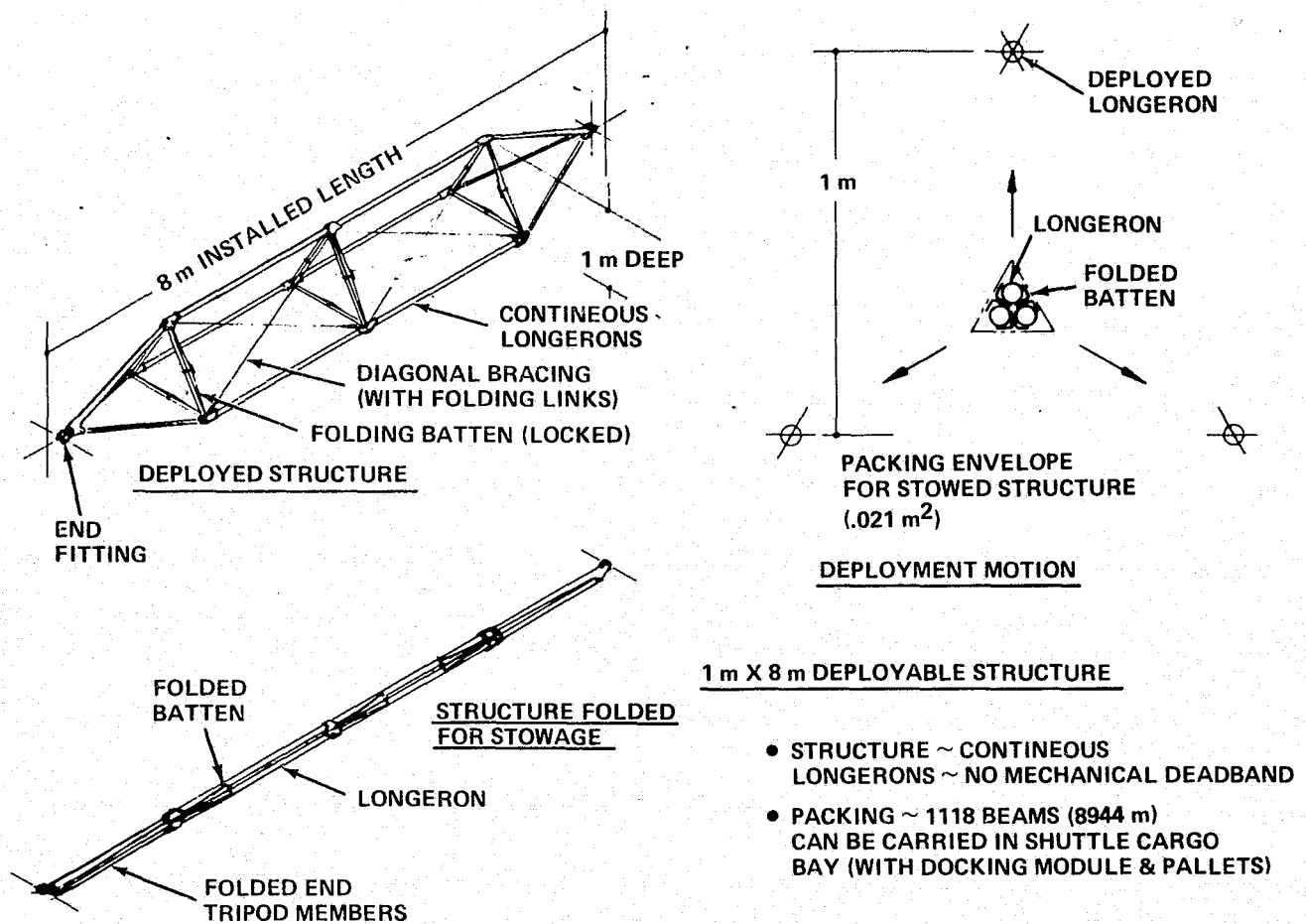


Figure 2-22 OCDA Candidate Structural Building Block

upper and lower tension rods are positioned and adjusted for length using the appropriate nodal clevis fitting. The element is removed from the fixture by the orbiter RMS and transported to the installation area.

The open cubes are removed from the subassembly fixture and transported to the assembly site for attachment to the existing structure. The open cubes are moved from the subassembly fixture by the orbiter manipulator, attached to a logistics traveler on the rotating boom, transported to the assembly site, and removed from the traveler by the boom manipulator which then positions the open cube for assembly.

Figure 2-24 illustrates the nodal joining of 8 m x 8 m x 4 m partial elements to form the full platform. A completed element corner tubular post, with crew toe holds or reaction hardpoints, was assembled and adjusted in the aft face of the cargo bay at the assembly fixture. The forward ends of two partially assembled cubes, with their appropriate probe fittings, are positioned and soft mated to the nodal drogue fitting. A final hard mate is made by turing a manipulator compatible device that is an integral part of the probe end fitting. The tension rods have a similar probe fitting that is soft mated and hard mated by a manipulator. The nodal drogue fitting, with 12 parts, is an integral part of the tubular vertical post. The probe is integral to the triangular beams and tension rods. These probes utilize spring-loaded pawls for capture and soft mate and drive mechanism that retracts the probe shaft until the pawls and probe anvil are seated in the drogue effecting the hard mate.

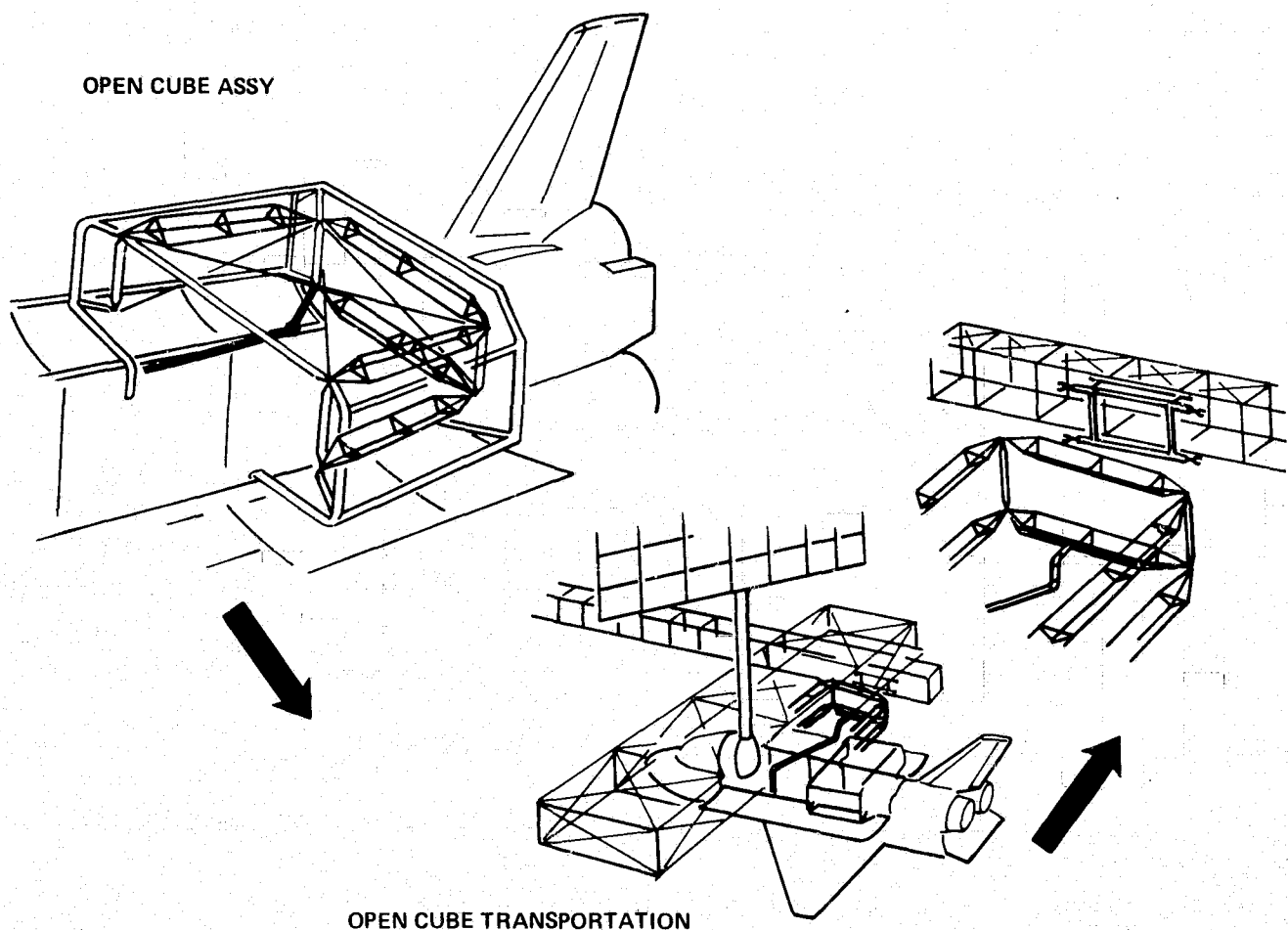


Figure 2-23 OCDA Platform Construction Sequence

2.8 DEMONSTRATION OBJECTIVES MET WITH INITIAL OCDA DEPLOYMENT

2.8.1 Objectives Met With OCDA

The goal of the Part I study was to embody as many construction technology objectives as was practical into the deployment of a demonstration article, which after deployment, can be used to further advance these construction technologies. The selection of the general purpose construction base that is tended by the Shuttle meets this goal. Other demonstration article approaches considered construction of end items, like a large solar array or antenna, directly from the Orbiter. It was found that these demonstration articles addressed a narrow set of demonstration objectives when compared to the overall needs of advancing all large structures technologies, and were found to be dead ended in terms of continued utility as a construction demonstration.

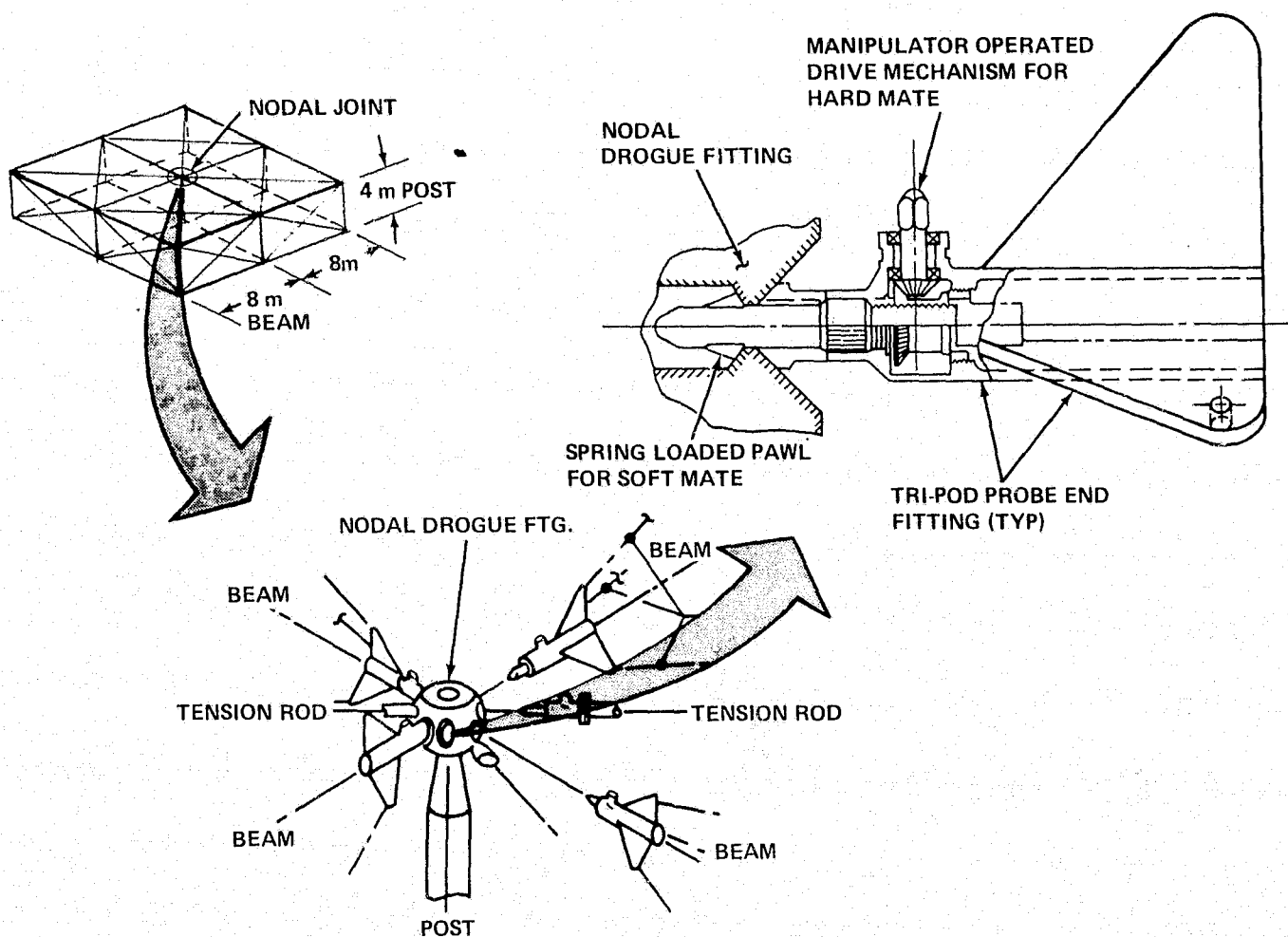


Figure 2-24 OCDA Platform Joining System (Centroidal Fitting) Design

The demonstration objectives met with the initial deployment of the OCDA are centered around seven of the twelve technical areas listed in Figure 2-4. These include the areas of large structures, large solar arrays, power distribution systems, propulsion, stabilization and control, assembly operations, and mission operation. These seven are common to all five of the representative future spacecraft studied while the remaining five are unique to one of the spacecraft and can be addressed as follow-on OCDA missions.

The OCDA platform can be built up out of a basic building block structure divided between deployables and space fabricated devices, though it may be advantageous to deploy the entire platform as will be shown in the discussion of follow-on missions. This feature of being able to use the platform as a test bed for evaluating several structural techniques meets a high percentage of the demonstration objectives in the field of large structures. Figure 2-25 lists some of these objectives. The technologies of man/machine productivity potential in a space environment is a key output of constructing the OCDA and is applicable to planning all future large structures design.

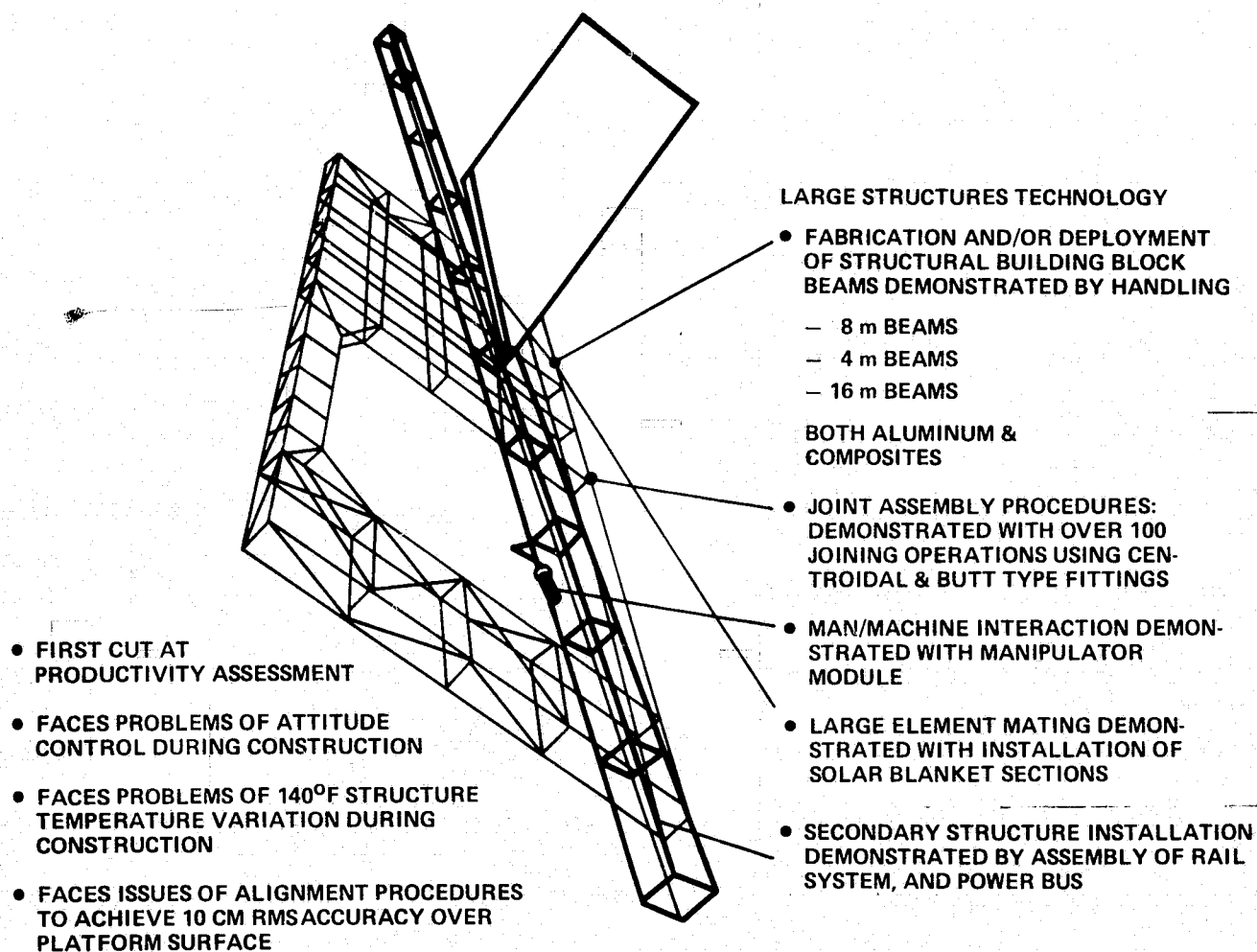
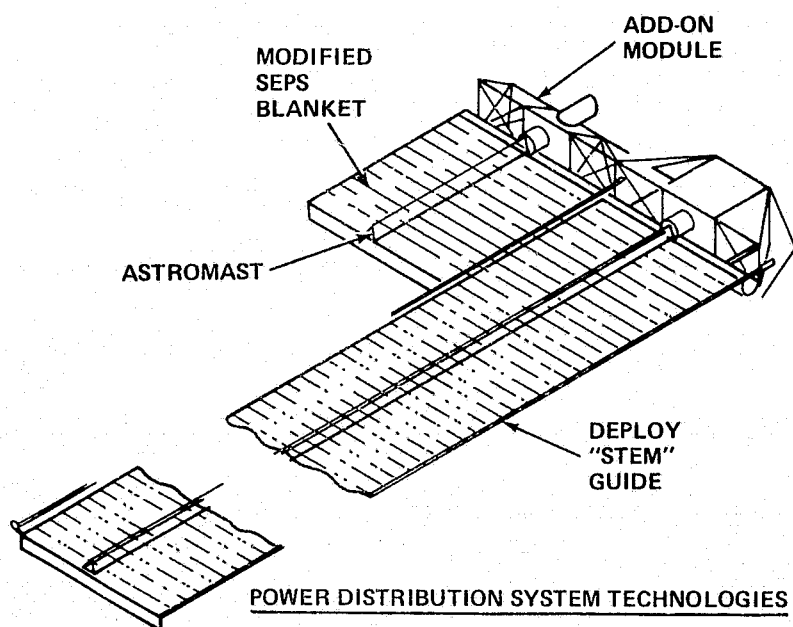


Figure 2-25 Key Large Structures Technology Objectives Met With OCDA Selected for Initial Deployment

Several key technologies that are addressed by constructing the OCDA in the areas of large solar arrays and power distribution are shown in Figure 2-26. One approach to deployment of a large area solar array is demonstrated, as well as interfacing a "ganged" array to the structure and power distribution system. Today's technology solar array is configured to operate at 200 volts but could be reconfigured to generate high voltages (20 kV) to evaluate switching and protection problems. Even at 200 volts, the installation of the bus system involves many issues associated with the future large scale Solar Power System. Construction operations and handling of the system with man's involvement should provide insight on developing necessary safety procedures.

Figure 2-27 summarizes the issues addressed in the areas of propulsion, including installation of tankage and feed lines. The resupply of propellants to maintain attitude control and station keeping is an integral part of the program. The control of a large flexible structure with a spacecraft exhibiting varying dimensions and inertia typified by the OCDA is similar to the conditions expected at the ultimate, future construction base for SPS.

Many of the basic construction operations associated with future construction bases will be used during OCDA assembly. The issues of resupply and storage, site logistics, site communications, power and



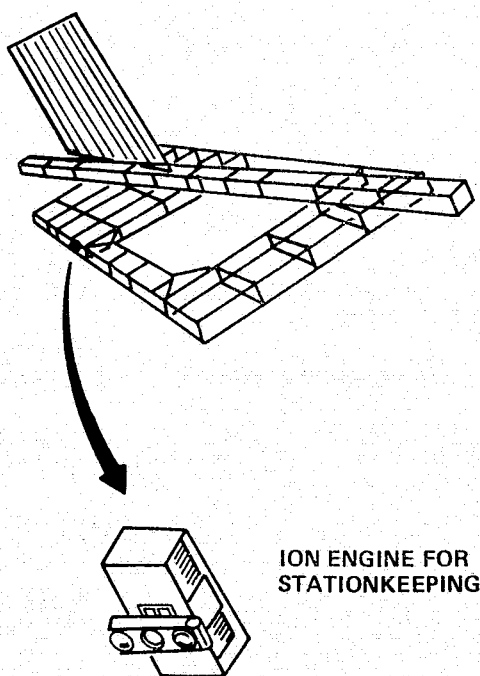
LARGE SOLAR ARRAY TECHNOLOGIES

- DEMONSTRATES ONE METHOD TO DEPLOY LARGE AREAS OF SOLAR BLANKET.
- DEMONSTRATES BLANKET INTERFACE WITH STRUCTURE, POWER BUS AND MONITOR/COMMAND SYSTEMS
- ADDRESSES ISSUES OF C/O AND FAULT ISOLATION
- COULD BE CONFIGURED TO OPERATE AT 20KV TO ADDRESS HI VOLTAGE ISSUES
- ADDRESSES THERMAL CYCLING ISSUES

POWER DISTRIBUTION SYSTEM TECHNOLOGIES

- DEMONSTRATES INSTALLATION OF BUS SYSTEM INCLUDING CONDUCTORS, POWER CONDITIONERS AND SWITCH GEAR
- ADDRESSES ISSUES OF ENERGY STORAGE FOR ATTITUDE CONTROL, SYSTEM HEATING, ETC.
- ADDRESSES ISSUES OF LARGE ROTARY JOINT INSTALLATION AND OPERATION
- ADDRESSES ISSUES OF C/O, FAULT ISOLATION & REPAIR

Figure 2-26 Key Large Solar Array and Power Distribution System Technology Objectives Met With OCDA Selected for Initial Deployment



PROPULSION TECHNOLOGIES

- DEMONSTRATES ON ORBIT INSTALLATION OF LOW THRUST PROPULSION SYSTEMS FOR ORBIT KEEPING & ATTITUDE CONTROL
- ADDRESSES ISSUES OF PROPELLANT RESUPPLY
- ADDRESSES ISSUES OF EXHAUST CONTAMINATION OF SOLAR ARRAY

STABILIZATION & CONTROL

- ADDRESSES ISSUE OF CONTROL OF LARGE FLEXIBLE STRUCTURE
 - LOCATION OF SENSORS & ACTUATORS
- ADDRESSES CONTROL ISSUES OF CONFIGURATIONS WITH CHANGING GEOMETRY DURING CONSTRUCTION & DURING OPERATIONS
- ADDRESSES DESIGN ISSUES OF ROTARY JOINT CONTROL & ACCURACY

Figure 2-27 Key Propulsion and Stabilization Objectives Met With OCDA Selected for Initial Deployment

signal routing, lighting, and safety will be resolved because of the OCDA endeavor. Valuable data on productivity in a space environment will be collected as well as data on the capabilities of man and machinery in constructing an integrated spacecraft in orbit. Because the OCDA will eventually be used as a platform for other construction activities, the issues associated with mounting construction equipments will be addressed and solved in a timely fashion.

2.8.2 Equivalent Sortie Missions to Meet Same Objectives

A number of demonstration objectives satisfied by the OCDA initial deployment could also be addressed through a series of Shuttle sortie missions. Figure 2-28 illustrates representative sortie mission concepts which could address technology demonstration issues in the areas of large structures, large solar arrays, power distribution, propulsion, stabilization and assembly operations.

Technology demonstration objectives that can be accomplished during construction of an OCDA with two to three Shuttle flights, would appear to need three or four Shuttle sortie missions to accomplish the same objectives. A major advantage, therefore, of the OCDA approach is that at the end of its construction period, NASA has an orbiting facility which can continue to be utilized to evaluate the question of what kind of factory is needed to cost-effectively perform the repetitive in-space manufacturing operations needed for SPS construction, and also be used to construct useful large communications and earth resource antennas.

● STRUCTURES TECHNOLOGY

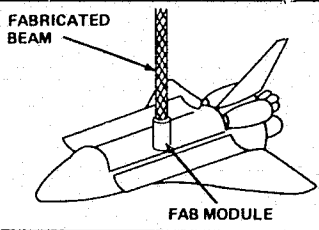
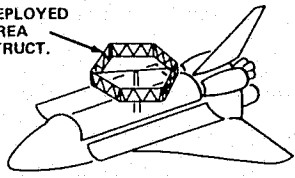
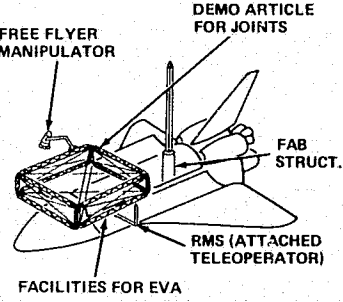
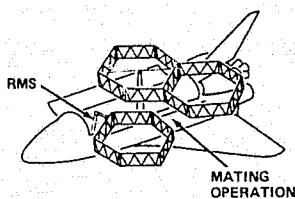
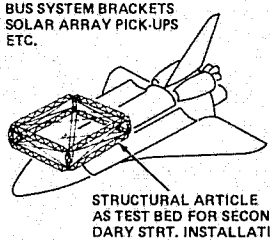
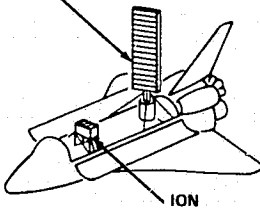
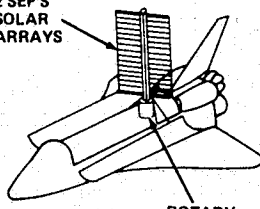
DEMO OBJECTIVES	SHUTTLE SORTIE CONCEPT	SHUTTLE FLTS REQ'D
1a — DEMONSTRATE FABRICATION OF BUILDING BLOCK STRUCTURE	 FABRICATED BEAM FAB MODULE	1 FULL FLIGHT
1b — DEMONSTRATE DEPLOYABLE BUILDING BLOCK STRUCT.	 DEPLOYED AREA STRUCT.	PARTIAL FLIGHT
2 — DEMONSTRATE & QUALIFY JOINT ASSEMBLY PROCEDURES 3 — DEMONSTRATE MAN-MACHINE INTERACTION 10 — DEMONSTRATE STRUCTURAL REPAIR	 FREE FLYER MANIPULATOR DEMO ARTICLE FOR JOINTS FAB STRUCT. RMS (ATTACHED TELEOPERATOR) FACILITIES FOR EVA	SEVERAL PARTIAL FLIGHTS
4 — DEMONSTRATE MATING OF LARGE ELEMENTS	 RMS MATING OPERATION	PARTIAL FLIGHT
5 — DEMONSTRATE INSTALLAT'N OF SECONDARY STRUCTURE	● BUS SYSTEM BRACKETS ● SOLAR ARRAY PICK-UPS ● ETC.  STRUCTURAL ARTICLE AS TEST BED FOR SECONDARY STRUT. INSTALLATION	SEVERAL PARTIAL FLTS
6 — MEASURE PRODUCTIVITY	INCLUDED IN ALL OF ABOVE	N/A
7.0 — DEMONSTRATE ATTITUDE CONTROL DURING CONSTRUCTION	INCLUDED IN ALL OF ABOVE	N/A
8.0 — DEMONSTRATE CONSTRUCT'N DURING THERMAL CYCLE OF ORBIT	INCLUDED IN ALL OF ABOVE	N/A
9.0 — TEST FOR STRUCTURAL ACCURACY & INTEGRITY	INCLUDED IN ALL OF ABOVE	N/A
10.0 — EVALUATE STRUCTURE/CONTROL INTERACTIONS	NEEDS FREE-FLYER LARGE STRUCTURAL ARTICLE FOR TEST	N/A

Figure 2-28 Sortie Flights Required to Address Same Demonstration Objectives Met With Three Flights Needed to Build OCDA

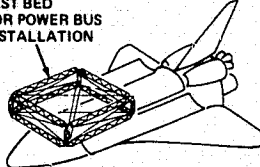
● PROPULSION TECHNOLOGY

DEMO OBJECTIVES	SHUTTLE SORTIE CONCEPT	SHUTTLE FLTS REQ'D
1 — DEMONSTRATE INSTALLATION OF PROPULSION UNITS 2 — DEMONSTRATE BENEFITS OF EXHAUST PRODUCTS ON PERFORMANCE OF — SOLAR BLANKETS — PWR CONVERTERS — POWER DISTRIBUTION (H/V VOLTAGE) 3 — DEMONSTRATE FAULT ISOLATION & REPAIR PROCEDURES	SEP'S SOLAR ARRAY  ION ENGINE BANK	PARTIAL TO FULL FLT

● SOLAR ARRAY TECHNOLOGY

DEMO OBJECTIVES	SHUTTLE SORTIE CONCEPT	SHUTTLE FLTS REQ'D
1 — DEMONSTRATE SOLAR ARRAY INSTALLATION PROCEDURE 5 — DEMONSTRATE SOLAR BLANKET INTEGRITY THROUGH ORBIT THERMAL CYCLE 6 — DEMONSTRATE ELECTRICAL INTEGRITY OF INSTALLED BLANKET SYSTEM 7 — DEMONSTRATE FAULT ISOLATION & REPAIR PROCEDURES	2 SEP'S SOLAR ARRAYS  ROTARY JOINT INSTALLAT'N	PARTIAL FLT

● POWER DISTRIBUTION SYSTEM TECHNOLOGY

DEMO OBJECTIVES	SHUTTLE SORTIE CONCEPT	SHUTTLE FLTS REQ'D
1 — DEMONSTRATE INSTALLATION OF BUS SYSTEM 2 — DEMONSTRATE INSTALAT'N OF PWR CONTROL, SWITCHING & PROTECTION DEVICES 3 — DEMONSTRATE INSTALLATION OF STORAGE DEVICES 4 — DEMONSTRATE FAULT ISOLATION & REPAIR	STRUCTURAL TEST BED FOR POWER BUS INSTALLATION 	PARTIAL FLT

● ASSEMBLY OPERATIONS TECHNOLOGY

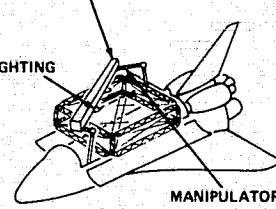
DEMO OBJECTIVES	SHUTTLE SORTIE CONCEPT	SHUTTLE FLTS REQ'D
1 — DEMONSTRATE PLACEMENT OF CONSTRUCTION BASE 2 — DEMONSTRATE LOGISTICS OPERATIONS OF CONSTRUCT'N BASE 3 — DEMONSTRATE RESUPPLY & STORAGE OPERATIONS 4 — DEMONSTRATE SITE COMMUNICATIONS OPERATIONS 5 — DEMONSTRATE INSTALLAT'N & USE OF SITE LIGHTING 6 — DEMONSTRATE REMOTE CONTROL OF MANIPULATORS 7 — DEFINE ROLE OF EVA IN CONSTRUCT'N BASE OPERATIONS	SIMULATE LONG BOOM LOGISTICS SYSTEM LIGHTING  MANIPULATOR REPRESENTATIVE CONSTRUCTION BASE STRUCTURE • SIMULATE STORAGE OF MATERIALS • SIMULATE FAPA POINTS FOR J165 & FIXTURES	FULL FLT.

Figure 2-28 (Continued)

Section 3

PART II (ADD-ON FIVE MONTH STUDY)

The first part of the study provided a baseline concept for developing and verifying space construction techniques. The Orbital Construction Demonstration Article (OCDA) selected was a small general purpose, Shuttle-tended construction base that enables more ambitious construction technology efforts to be undertaken than with single sortie flights. The purpose of the add-on study was to define the follow-on uses of the OCDA and to delineate the impacts these uses have on the baseline OCDA design.

The six tasks performed during the add-on study effort are outlined in the schedule shown in Figure 3-1. Tasks A and B were performed in parallel where the mission analysis effort was augmented by design concept studies performed under Task B. Operations studies (Task C) defined the assembly and test operations required to perform the follow-on activities. Task D performed the cost estimating and programmatic functions to provide end to end program descriptions of three basic OCDA/Follow-on Program Scenarios. Task E evaluated the impact the follow-on activities have on the OCDA size and power requirements, while Task F compiled all requirements into a Requirements Document (Volume III of this Final Report).

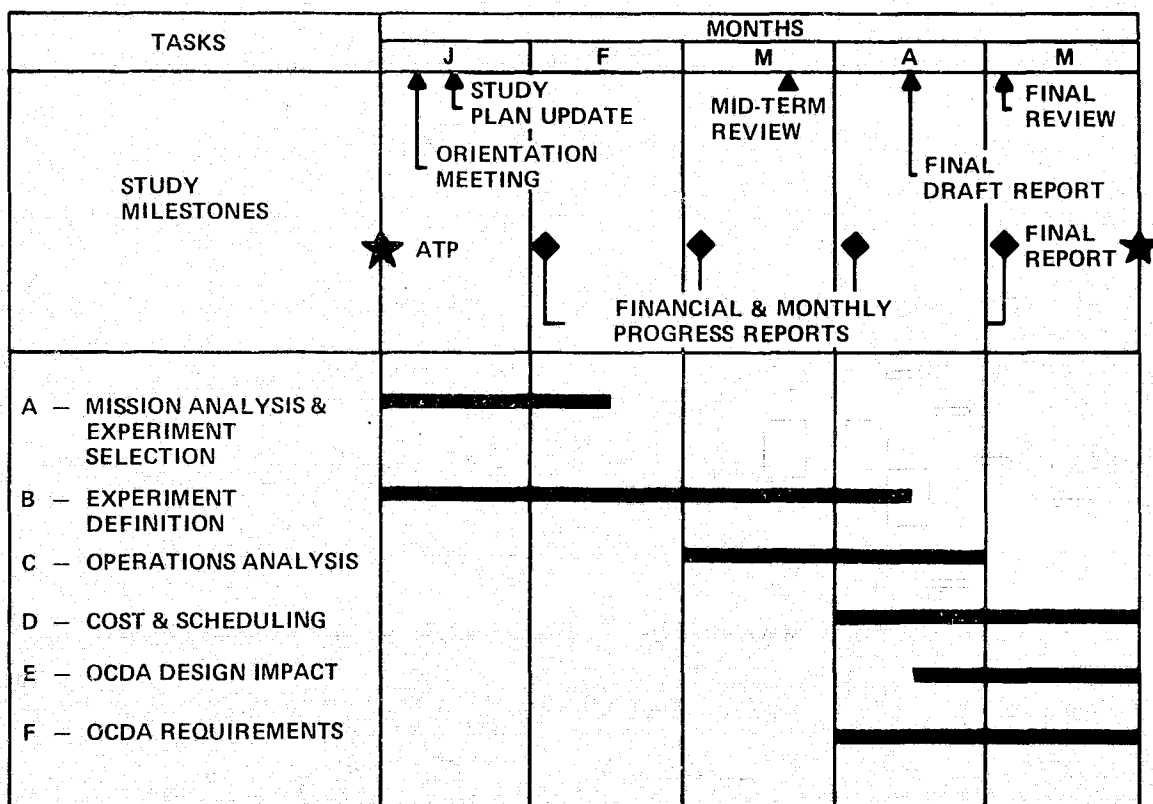


Figure 3-1 OCDA Study Add-On Schedule

3.1 FOLLOW-ON PROGRAM SCENARIOS STUDIED

The three Program Scenarios selected for the study of OCDA follow-on mission potential are outlined in Figure 3-2. Programs 1 and 2 emphasize solar power development, while Program 3 utilizes the OCDA to build large antennas. The major difference between Programs 1 and 2 is that Program 1 utilizes the OCDA construction facilities to build an SPS pilot plant, while Program 2 utilizes the OCDA large power source and construction potentials to address SPS related technologies at an element level.

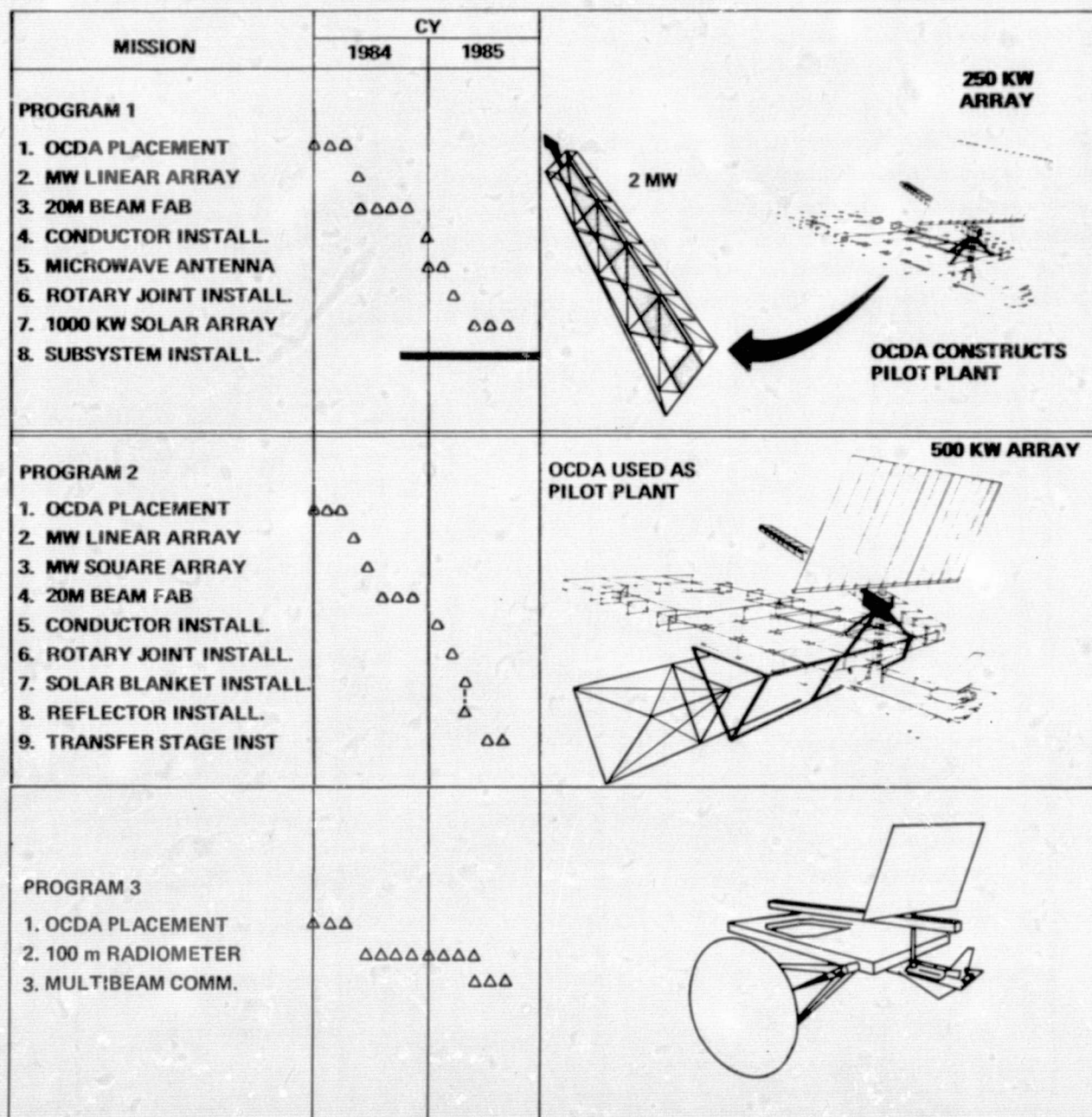


Figure 3-2 Program Scenario Options Studied to Date

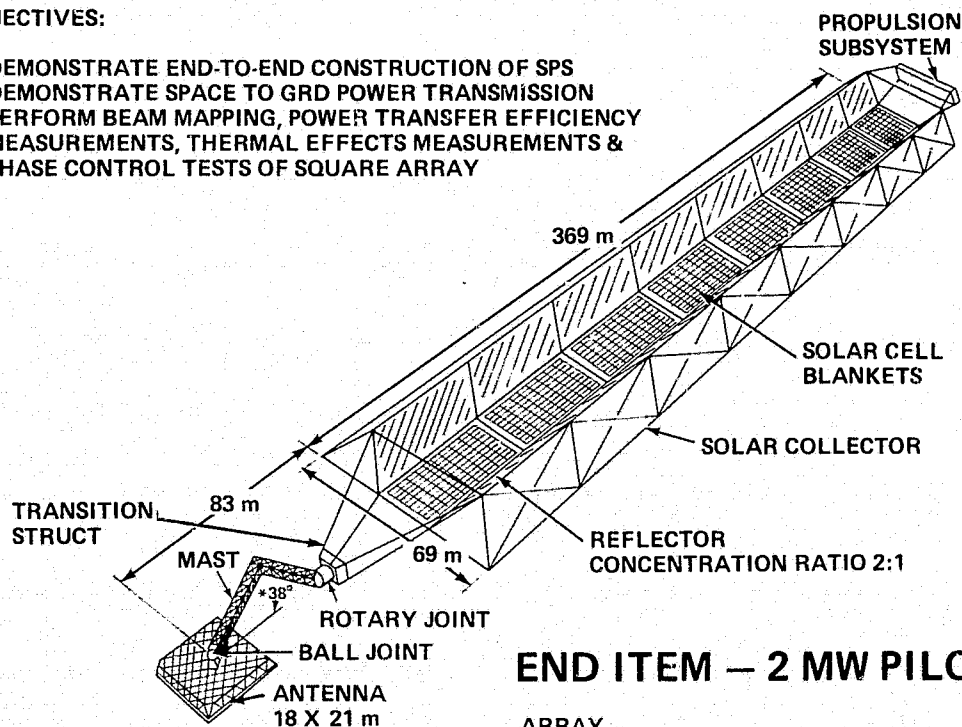
Program 1, with eight basic missions (seven follow-on missions) leads to construction of a 2 MW solar array along with a 21 m x 21 m square transmit antenna. This independent SPS pilot plant can transmit 10 to 50 kW of demonstratable power to the ground over a brief period. Precursor technology activities are included as Missions 2 and 3. The first follow-on mission (Mission 2) utilizes an amplatron powered linear array and the OCDA power source to test the phase control aspects of the SPS transmit antenna. Mission 3 is used to assemble the jigs, fixtures and machinery which, in turn, is used to fabricate a 20-m deep structural element. This equipment is used later in the program to construct the large 2 MW solar array. Missions 4 through 8 are actual construction of the 2 MW pilot plant, starting with fabrication and installation of the power bus system to the support structure.

Program 2 can meet many of the SPS related demonstration objectives embodied by Program 1 with the exception of demonstrating power transmission to the ground. This program starts with a larger OCDA power source (500 kW) and emphasizes microwave testing using klystrons. Fabrication experiments are done at an element level using the basic jigs and fixtures of the 20-m beam fabricator. Program 2 includes a mission for demonstrating the installation of a relatively large electric propulsion unit.

Program 3 emphasizes construction of large antenna. Mission 2, requiring 8 seven-day Shuttle flights, is used to construct a tight tolerance (rms surface error = 0.24 cm) radiometer reflector with an aperture diameter of 100 m. Mission 3 constructs a 61 m diameter multibeam communications antenna which utilizes a bootlace lens concept for a single aperture and multiple feed elements at the lens focus.

OBJECTIVES:

- DEMONSTRATE END-TO-END CONSTRUCTION OF SPS
- DEMONSTRATE SPACE TO GRD POWER TRANSMISSION
- PERFORM BEAM MAPPING, POWER TRANSFER EFFICIENCY MEASUREMENTS, THERMAL EFFECTS MEASUREMENTS & PHASE CONTROL TESTS OF SQUARE ARRAY



END ITEM — 2 MW PILOT PLANT

ARRAY

• BLANKET	6712 Kg
• CONCENTRATOR	1534 Kg
• STRUCT & BUS SYSTEM	3722 Kg
• ANTENNA INTERFACE & ROTARY JOINT	5814 Kg

ANTENNA

10521 Kg

TOTAL

28303 Kg

Figure 3-3 Program Scenario 1 End Item—2 MW Pilot Plant (Major Difference Between Programs 1 and 2)

3.2 DIFFERENCES BETWEEN PROGRAM SCENARIOS 1 AND 2

Both Program Scenarios 1 and 2 emphasize technology advancement of the SPS. The major difference is that Program Scenario 1 uses the OCDA to construct an independent SPS pilot plant with the characteristics shown in Figure 3-3. The SPS pilot plant uses a silicon solar array that operates at a concentration ratio of two to generate 2 MW of power. The rf output power of this satellite is 1 MW using conservative estimates of efficiency for the rf converters, rotary joint and power distribution system. The overall satellite mass, excluding avionics and propulsion, is 28,303 kg.

At an altitude of 350 km, the maximum potential power density on the ground varies as a function of solar array size and transmit antenna dimensions. At an aperture dimension of 20 m and a power output of 1 MW, the incident rf power density of 0.011 mW/sq cm can be expected at a ground rectenna. At this power density, a rectenna can operate at 45% efficiency.

Orbit to ground geometries would result in periodic passes of the pilot plant over the ground receiving station providing a power transmission demonstration of no more than two minutes. Many technical problems would exist in terms of antenna steering control and phase control lock-on that are not issues for the ultimate geosynchronous orbit SPS. If a space-to-ground power transmission demonstration is needed to prove SPS viability, the solar array and antenna sizes selected can provide sufficient power on the ground for a demonstration. Greater analysis is needed to determine if the dynamics, both orbital and vehicle, can be managed before a program of this nature is pursued.

OBJECTIVES:

- SPS CONSTRUCT'N TECHNOLOGY ADVANCEMENT THRU ELEMENT TESTING
- MICROWAVE TESTING USING OCDA POWER SOURCE

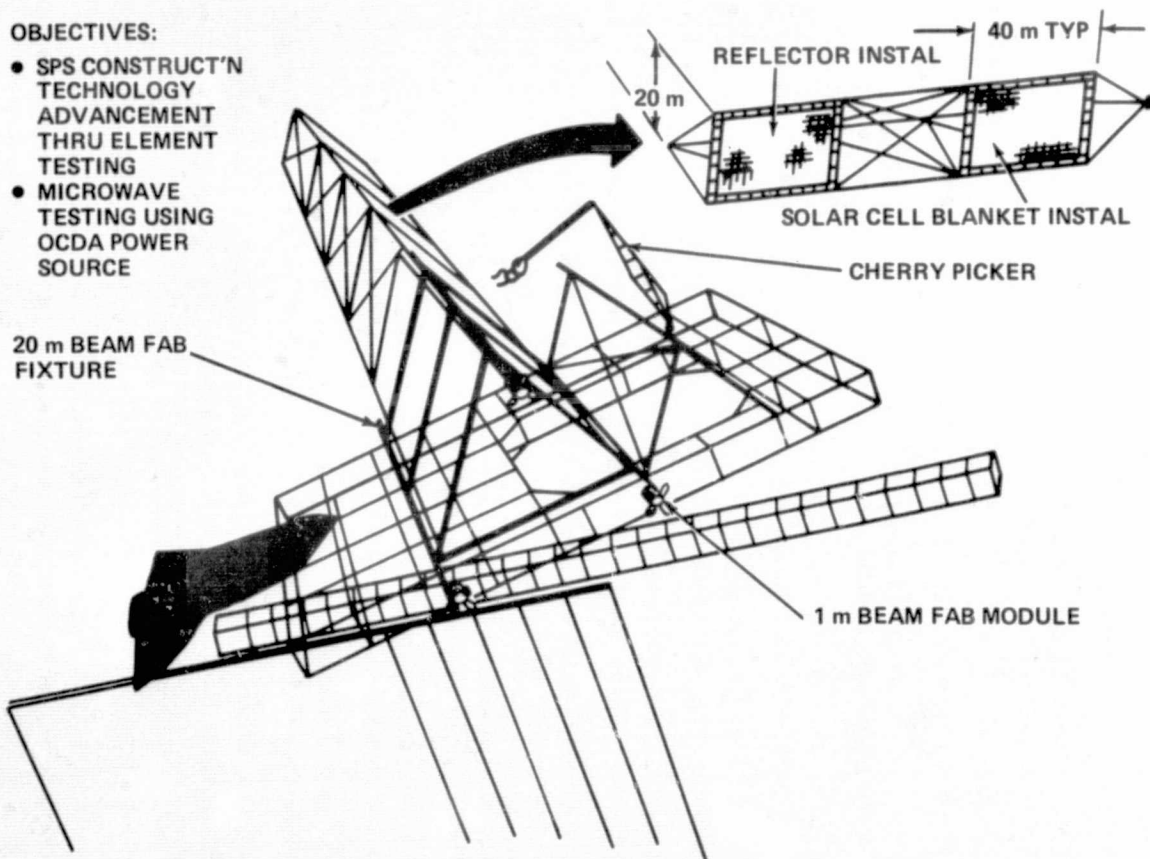


Figure 3-4 Program Scenario 2

Program Scenario 2 uses basically the same construction equipments as Program 1, but stops at the construction of a 20-m deep beam. The demonstration objectives for mounting solar blankets and reflector surfaces to structure are addressed using the configuration shown in Figure 3-4. The jigs, fixtures and support systems, such as manipulator cherry picker, are augmented by a system of solar blanket and reflector dispensers that utilize the side of the 20 m beam to simulate the synchronized fabrication of structure and secondary installations. Program 2 addresses SPS construction technologies as does Program 1, but does it at an element level.

3.2.1 Microwave Transmission Testing

Both Programs 1 and 2 contain precursor microwave transmission experiments centered around testing the phase control of the ultimate SPS with a linear array. The importance of this function, that of focusing and steering the microwave beam with a phased array constructed in orbit, was judged critical enough to warrant an initial experiment before advancing to other SPS related construction experiments.

The OCDA rotating boom was found to have the rigidity to act as the support structure for this experiment. The linear waveguide with antenna ground plane was mounted to the rotating boom (Figure 3-5) via a screw jack system that allows alignment of the system to an accuracy of 1 arc minute after construction. The control electronics are mounted to the side of the boom and receive phase control signals from a beam mapping satellite located in a stable orbit 48 km away.

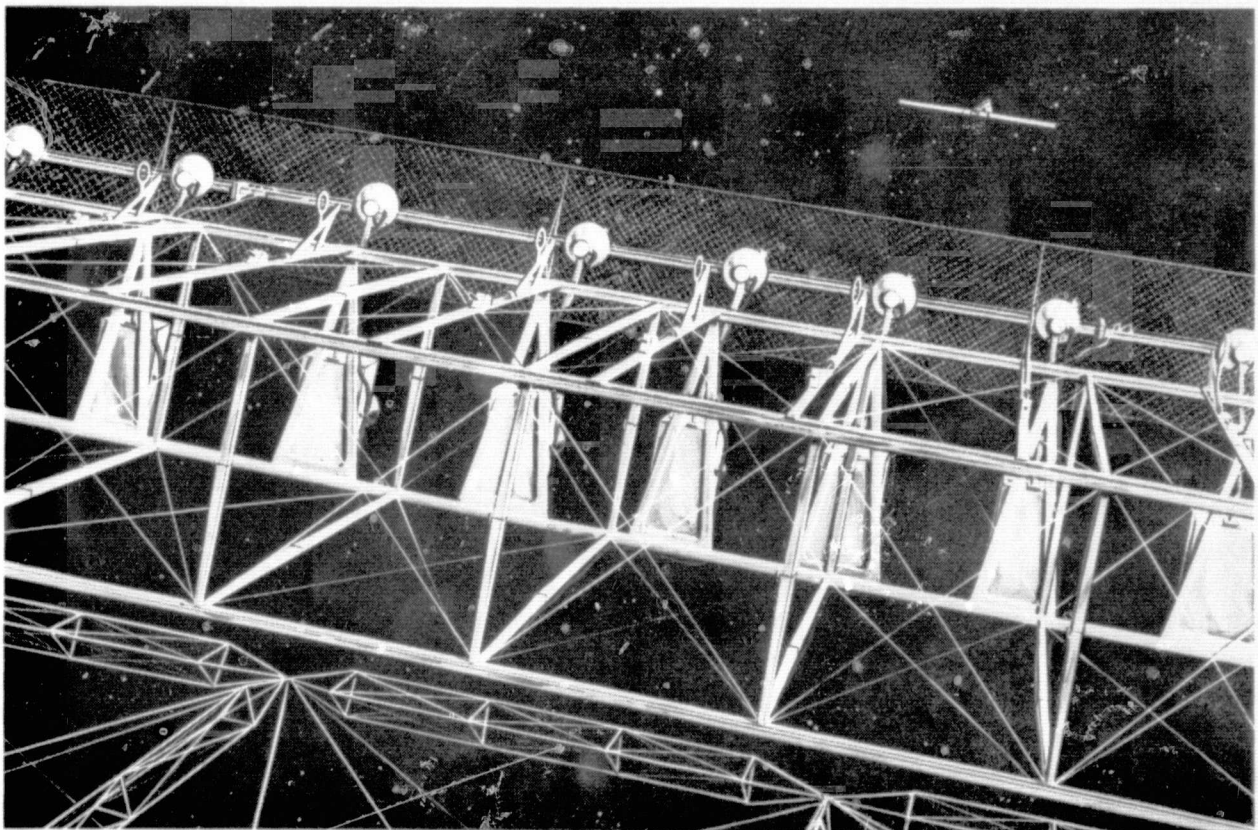


Figure 3-5 Linear Phased Array for Microwave Focusing and Steering Experiment

Figure 3-6 amplifies the differences between the linear array test in Programs 1 and 2. The Program 1 concept is limited to the test of amplitrons and is set up as a tapered rf system in ten steps. The maximum power density at the center is 22 kW/sq m while the edge waveguide section operates at a power density of 2.6 kW/sq m. The Program 2 concept utilizes klystrons in a five step taper with approximately the same central and edge power densities.

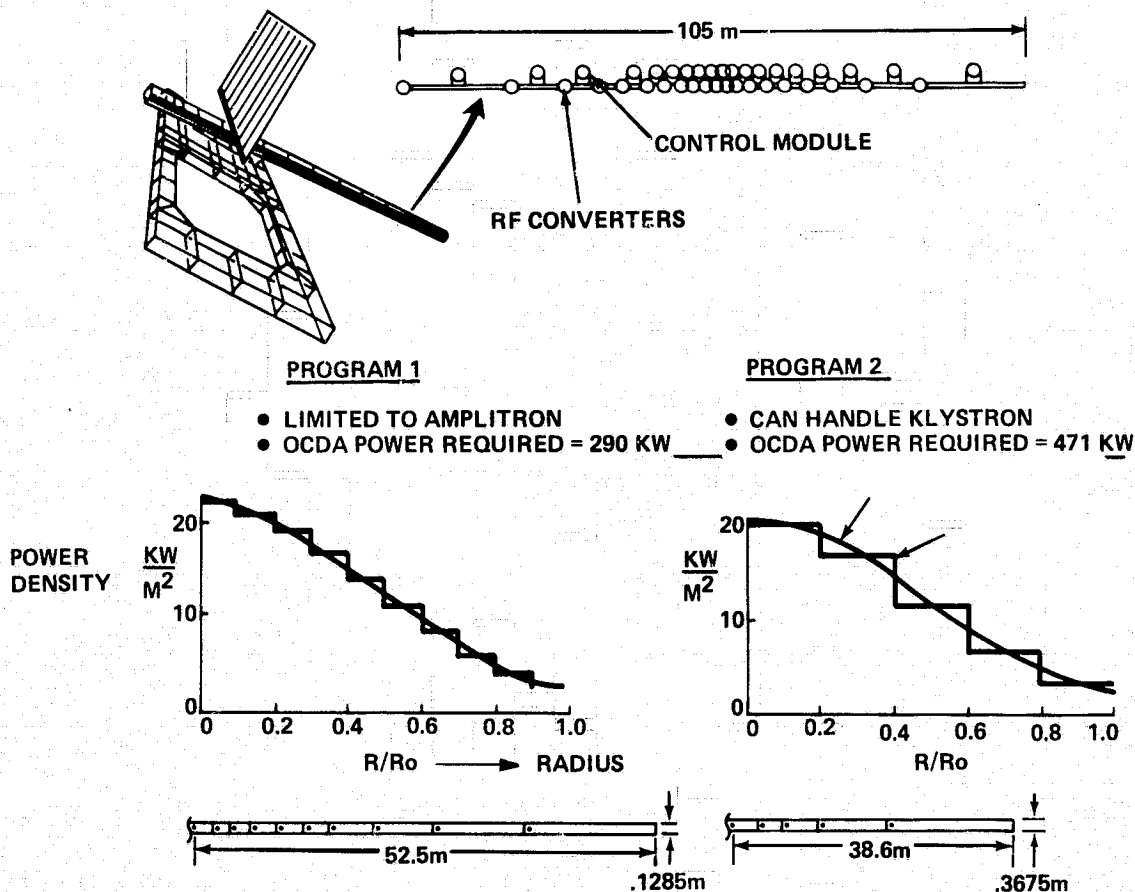


Figure 3-6 Microwave Linear Array Differences

The amplitron antenna is one waveguide wide (0.1225 m) using a 5 kW power added device for each waveguide segment. The klystron configuration utilizes an antenna with three parallel waveguides using a 46 kW klystron operating at half power for each subarray. At these power levels and transmit antenna dimensions, Program 1 requires an OCDA with a 290 kW solar array while Program 2 needs a larger 471 kW power source, assuming that the tests are performed while the OCDA is in sunlight.

Evaluation of the signal transmitted from the linear array is accomplished by use of a beam mapping satellite. The satellite travels in an orbit identical to the OCDA and appears stationary to the transmitting antenna. The beam is mechanically pointed at the satellite by a combination of OCDA boom rotation and platform attitude maneuvers.

The boom length on the mapping satellite is large enough to span a significant portion of the linear array signal. The signal is mapped in the antenna far field (i.e., at a distance great enough to reduce the phase difference between signals from the center and the edge of the linear array to an acceptable level).

Analysis of the beam pattern is enhanced by mapping two sidelobes to keep the mapping satellite boom length within a reasonable size of 315 m.

Programs 1 and 2 both incorporate a test of a two-dimensional transmit antenna. Figure 3-7 presents the differences in the square arrays. The 20-m square array for Program 1 is mounted to the independent SPS pilot plant and is configured for 1 MW output power using amplitrons. The 6-m square antenna used in Program 2 uses the OCDA power source and klystrons.

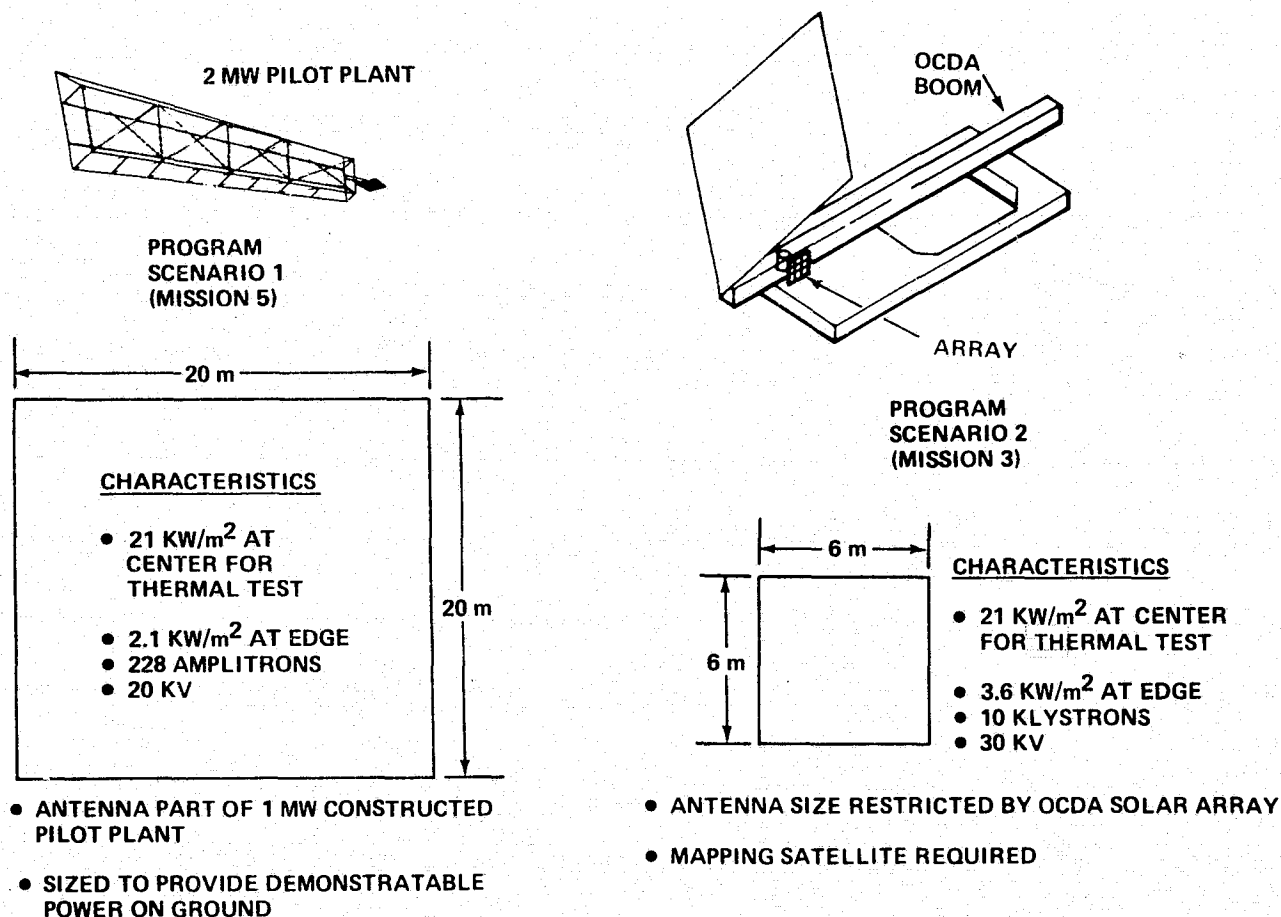


Figure 3-7 Microwave Transmit Antenna Square Array Differences

The objectives of these missions is to test transmission efficiencies and to determine thermal interaction between the high power density sections of the antenna and the structure/waveguides. Program 1 performs transmission to the ground while Program 2 performs transmission tests using the free-flying mapping satellite that was used in the linear array experiments discussed previously.

The antenna structure used in Program 1 is constructed out of 3-m long rods, geometrically configured in octahedra and tetrahedra (oct-tet). It is planned to be deployed to final size in a single operation. The antenna is attached in the OCDA platform hole on a pivot system to allow access to both faces on the antenna for assembly of the waveguide subarrays on one side and the installation of the power bus system on the other.

The 6 m x 6 m microwave antenna used in Program 2 is installed on the OCDA boom at the central mast. Total mass of the test article is 3283 kg. With a 257.4 kW input to the klystrons, 195 kW rf energy is propagated by the square array for a system efficiency of 78%. The power density profile of the antenna

was chosen to simulate the maximum thermal gradient between the center and edge of the ultimate SPS transmit system. The mapping satellite used to control the linear array in a previous test is located 1500 m from the 6 m x 6 m antenna to measure system efficiency at a received power density of 20 mW/sq cm.

3.2.2 Space Fabrication

The fabrication equipments used in Program 1 are more complex than those used in Program 2, but more closely simulate the integrated fabrication process needed for verifying productivity of the ultimate SPS. Figure 3-8 summarizes the differences in these equipments. Program 2 utilizes the frames and equipment needed to fabricate a 20-m beam. Program 1 adds a holding fixture to the basic 20-m deep beam fabrication unit so that after completing one 360-m long beam it can be moved and held to the side so that a second beam can be fabricated. The two beams then form the primary structure for the 2 MW pilot plant solar array.

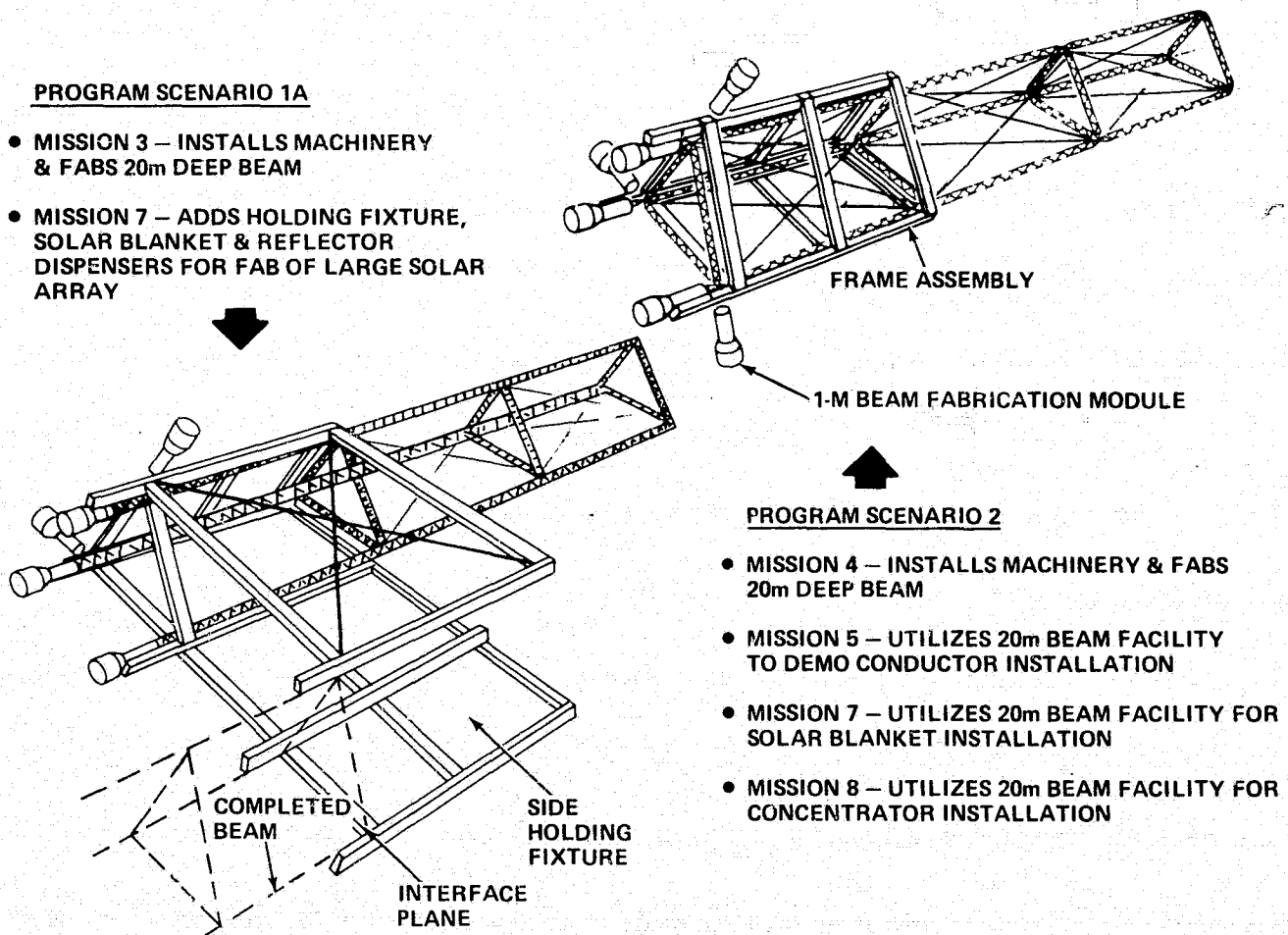


Figure 3-8 Space Fabrication: Simulate Ultimate SPS Solar Array Production

The 20-m beam fabrication module arrangement used in Program 2 (see Figure 2-10) consists of a 58-m long structural frame assembly which is erected from shuttle delivered prepackaged deployable structures. The frame assembly provides mounting and support for four 1-m beam fabrication modules which simultaneously produce the 1-m longeron caps and battens of the 20-m beam. The 20-m fabrication

module is attached to the OCDA platform nodals and is located on the platform side opposite the rotating solar array. This location of the module doesn't restrict the OCDA boom rotation and doesn't require an increase in platform length. To assemble and erect the 20-m fabrication module (factory) a cherry picker and track system are required because of the limitations (reach and location) of the OCDA rotating boom manipulator. The factory cherry picker support structure (deployables) is attached to the platform nodal points and is located adjacent to the fabrication module.

The configuration of equipments needed for automatic construction/fabrication of a 2 MW pilot plant (Program 1) is shown in Figure 3-9. The configuration consists of a fixture (factory) required to fabricate the pilot plant structure and provide for the automatic installation of solar cell/reflector blankets and power conductors. The factory employs a 20-m beam fabrication module, a cherry picker and track system. The 20-m beam fabrication module consists of a frame assembly which provides mounting and support for six 1-m beam fabrication modules which simultaneously produce the three longerons and battens of the 20-m beam. An additional 1-m beam fabrication module is used to produce the lateral stitch beams which tie the two 20-m beams together to form the pilot plant structure. Mounted adjacent to one of the 1-m longeron fabrication modules is a power conductor fabrication module and conductor installation mechanism. A 20-m beam return guide consisting of a structure (deployable) similar to that of the fabrication module frame assembly is added. The return guide and the 20-m beam fabrication module are structurally tied together to form the factory fixture and ensure alignment of the pilot plant structure. Attached to the factory fixture are two reflector blanket modules and one solar cell blanket module. These modules dispense the blankets in synchronization with the emerging pilot plant structure and an installer attaches the blankets to the structure.

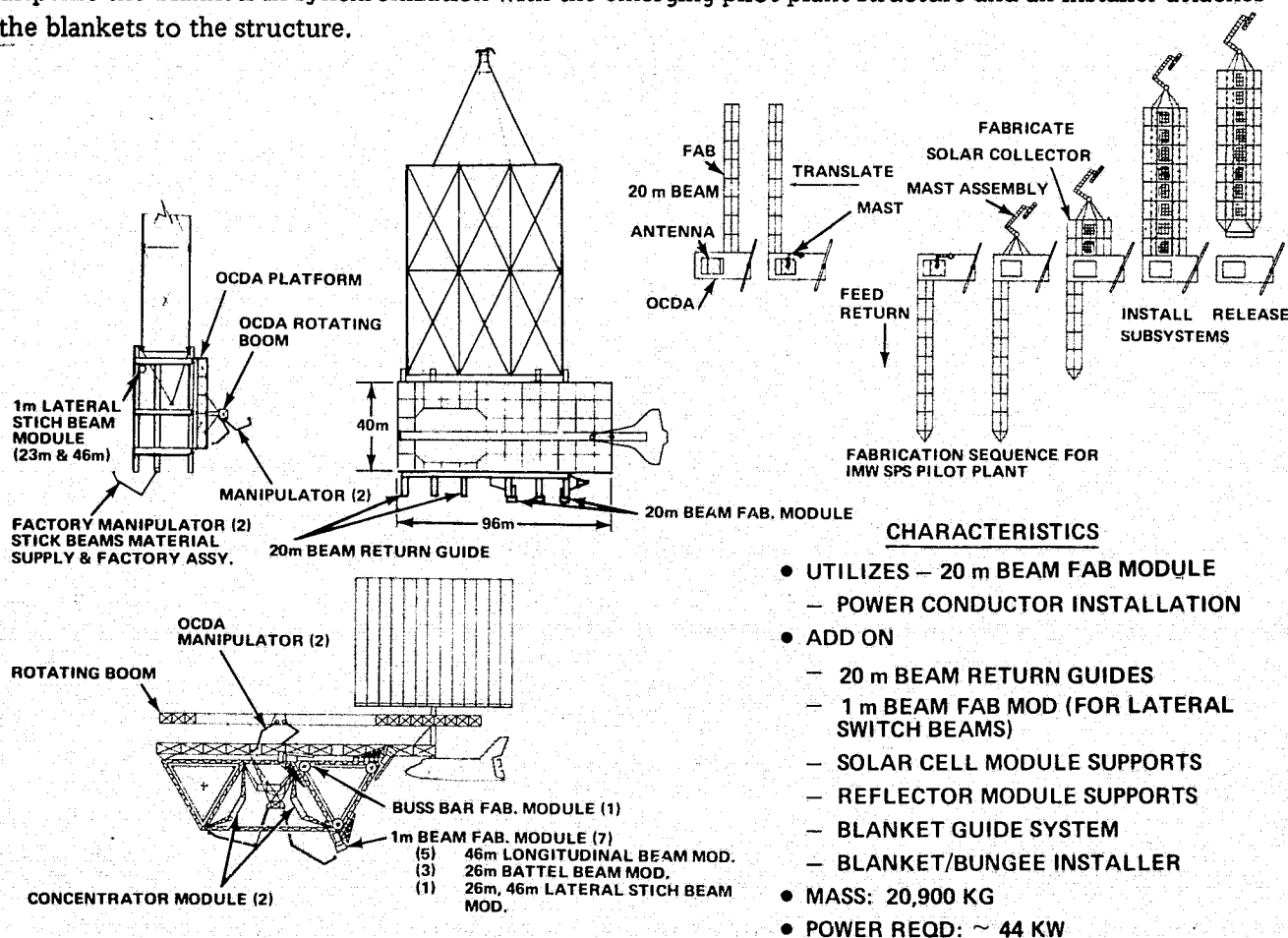


Figure 3-9 2 MW SPS Pilot Plant Fabrication Unit Used on Program 1

3.2.3 Subsystem Installation Experiments

The advancement of SPS construction technologies requires demonstrating the installation of several major subsystems to the supporting structure. This includes the synchronized installation of the power bus system, the solar blankets and reflecting surfaces to the structure as the structure is being produced. Another key installation is the mating of the rotary joint to solar array structure, followed by the interface of the power systems. Installation of high performance propulsion units for attitude control and station keeping is another key construction issue.

Figure 3-10 illustrates how the conductor installation will be synchronized with the fabrication of the 20-m beam in both Programs 1 and 2. The illustration shows how conductor fabrication modules are incorporated into the 20-m fabrication fixture so that they can be synchronized with the 20-m fabrication modules. As the 20-m truss elements are manufactured, the conductor elements are also fabricated. Automated support link installation stations are provided for the attachment of the aluminum conductors to the 20-m cap members. The ability of the metal conductors to grow and move as a function of thermal variations produced by the current flow and/or thermal environment is provided by the expansion bellows and a swing link-support attachment structure.

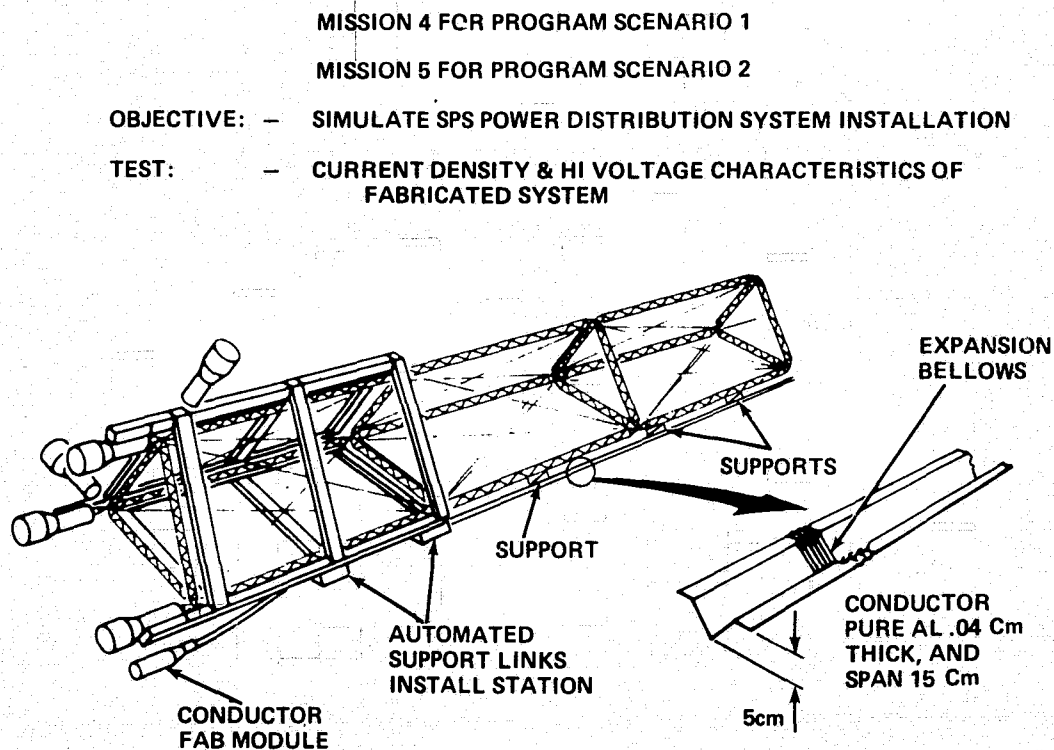


Figure 3-10 Conductor Installation

After conductor installation, the integrity of the system is verified by conducting high currents and voltages through the system. A current density of 795 amp/sq cm is provided by the OCDA solar array and inspections and measurements are made to verify that local hot spots at joints are within specification. High voltage (20 kV to 40 kV) integrity of the system is also checked, and effects such as local plasma interaction and electrostatic charges are observed.

The demonstration of installing solar blankets and reflector surfaces is undertaken differently in Programs 1 and 2. These installation functions are an integral part of the fabrication process needed to construct the 2 MW solar array Program 1. The installation process is synchronized with the 20-m deep beam fabricator. In Program 2, a small section of solar blanket and reflector surface is installed to one side of the 20-m beam using equipments similar to those used in Program 1.

The solar cell blanket and reflecting surfaces are attached to the 20-m beam caps by bungees. This approach maintains blanket flatness and eliminates the extreme stresses that would be induced into the beam caps if the blanket was rigidly attached during light/dark thermal cycling. The blanket configuration provides a reinforced edge for attachment of the bungee to the blanket. The blanket is folded and rolled onto a module for shuttle delivery to the OCDA. The 20-m beam fabrication module frame assembly provides for the mounting and support of the blanket module. Installing the solar cell blanket during fabrication of the 20-m structure consists of unrolling the blanket in synchronization with the structure fabrication. As the blanket is unrolled, assembly of the bungees to the blanket is accomplished using the bungee stowed in cassettes mounted adjacent to the blanket module; each of the assembled bungees is then picked up by a guide track which unwraps the blanket and delivers the blanket edge to its proper structural interface where a bungee installer attaches the blanket to the emerging structure.

Mission 6 in both Program Scenarios 1 and 2 demonstrates installation of a scaled down SPS rotary joint and tests the unit's electrical characteristics after assembly. The differences in approach between Programs 1 and 2 are conceptually shown in Figure 3-11. In Program 1, the rotary joint is integrated to the 2 MW solar array and 21-m aperture transmit antenna. In Program 2, the rotary joint is interfaced to a partially fabricated 20-m truss girder, and load banks added to the rotary joint to perform electrical tests.

ROTARY JOINT INSTALLATION

OBJECTIVE — EVALUATE THE OPERATION OF A SCALED DOWN ROTARY JOINT MECHANICAL & ELECTRICAL INTERFACES.

TEST REQUIREMENTS —

- VERIFY INSTALLATION PROCEDURES
- VERIFY MECHANICAL OPERATION OF THE BALL JOINT DRIVE AND SUSPENSION SYSTEM.
- VERIFY POWER TRANSFER THROUGH THE ROTARY JOINT 40KVDC & 7.75 AMPS/CM² PER BRUSH

PROGRAM SCENARIO 1A

- END-TO-END INTEGRATION OF ROTARY JOINT WITH SOLAR ARRAY & ANTENNA

PROGRAM SCENARIO 2

- UTILIZES 20M BEAM AS BASE & OCDA POWER SUPPLY FOR ELECTRICAL TESTS

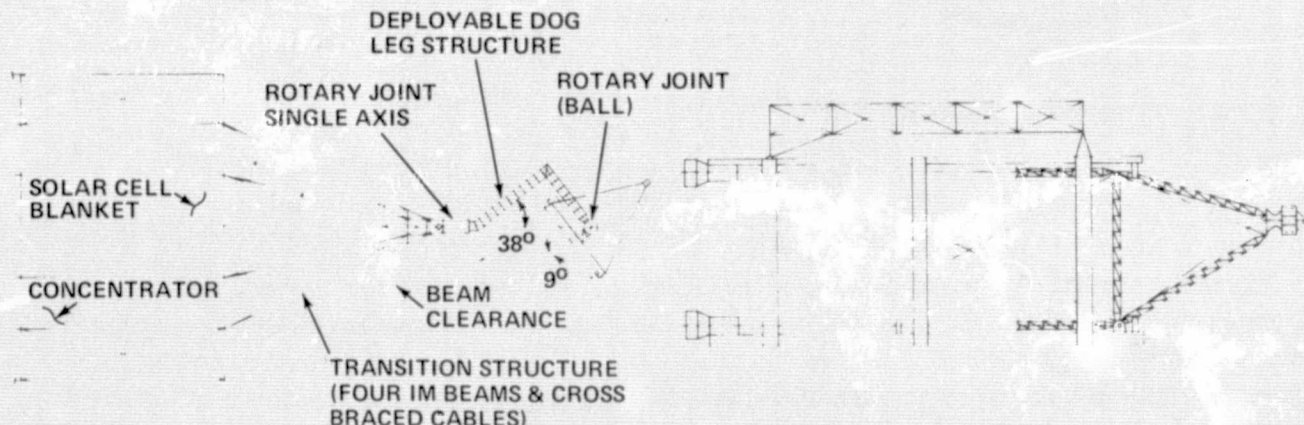


Figure 3-11 Rotary Joint Installation Differences

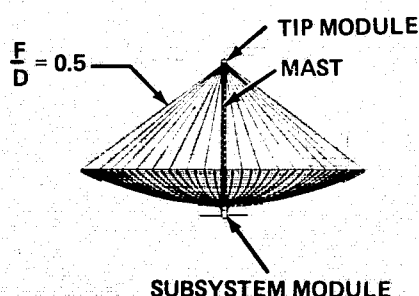
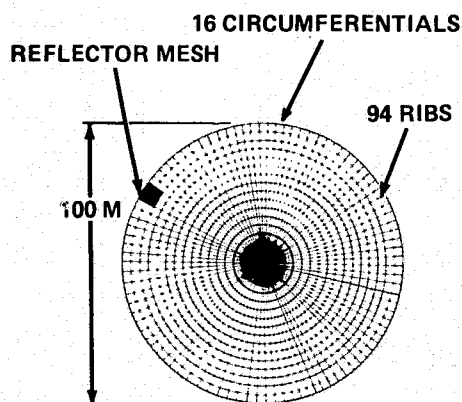
The objective of Mission 9 in Program 2 is to demonstrate the installation of high performance electric propulsion units to a large structure and then to perform maneuvers to evaluate dynamic interaction between the maneuver system and the flexible structure.

3.3 PROGRAM SCENARIO 3 – LARGE ANTENNA CONSTRUCTION

3.3.1 Radiometer

The characteristics of a 100-m parabolic antenna for earth resource observation which provides data on soil moisture, salinity and weather conformation are summarized in Figure 3-12. This antenna is designed to operate at a frequency of 2.5 GHz with an rms surface accuracy of $\lambda/50$ and a focal length-to-diameter equal to 0.5.

The antenna configuration consists of a core module housing a subsystem module, central mast (deployable), tip module and reflector support hub. The parabolic reflector consists of a reflector mesh and its supporting structure of 94 radial ribs and 16 rings (circumferentials). The parabolic shape of the flexible reflector mesh is maintained by a contour control system which employs a thermal expander device.



ELEMENT	MASS ESTIMATE	
	Kg	LBM
• ANTENNA	(6238)	(13755)
– SURFACE MESH	200	441
– STRUCTURE		
○ CIRCUMFERENTIALS	460	1,014
○ RIBS	3,778	8,330
– HUB	600	1,323
– MAST	200	441
– MECHANICAL SYST	1,000	2,205
• SUBSYSTEMS	(965)	(2128)
– STRUCTURE/THERMAL CONTROL	200	441
– ATTITUDE CONT (ACS)	40	88
– COMM	200	441
– ELECT POWER	180	397
– DATA MANG (DM)	315	695
– SENSORS	30	66
TOTAL	(7203)	(15883)

Figure 3-12 100 m Radiometer Configuration

Figure 3-13 describes the arrangement of the OCDA and the completed radiometer in its checkout configuration. The antenna checkout will be via a subsatellite. The multi-mission modular spacecraft (MMS) currently being developed is very well suited for this purpose. Antenna pattern and overall performance tests are conducted by commanding rf emitters covering the frequency spectrum of interest to transmit conformation and measure the antenna pattern, as well as the frequency response and the overall

handling of the data by the on-board data management subsystem. Final adjustments and replacement of components as indicated by tests would be facilitated by having the radiometer attached to the OCDA.

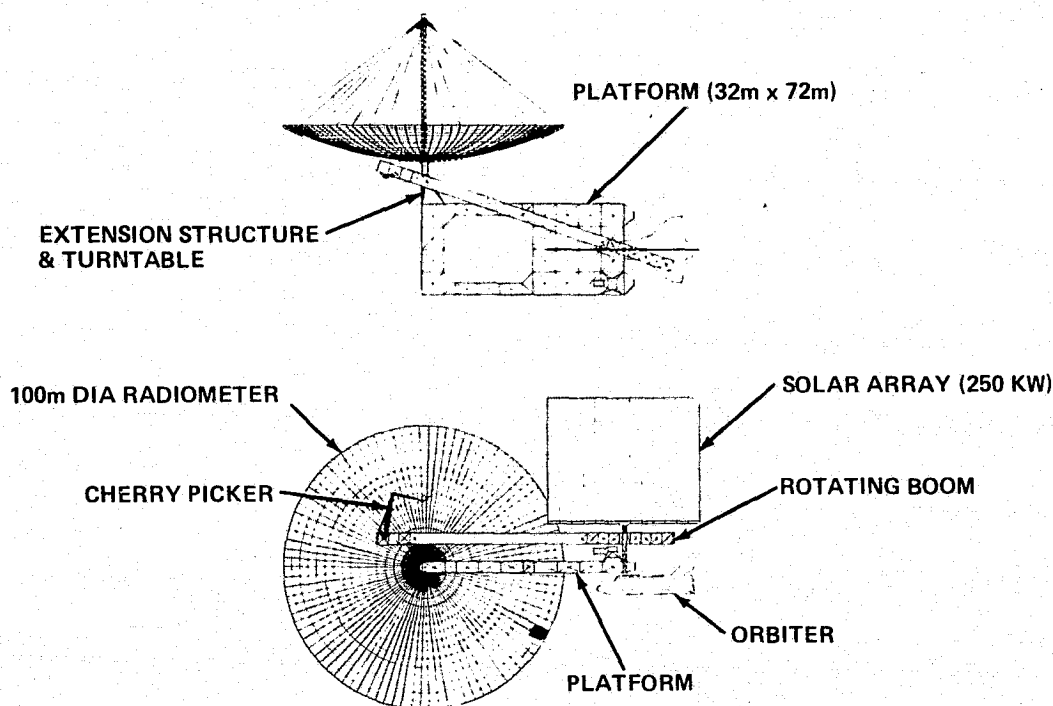


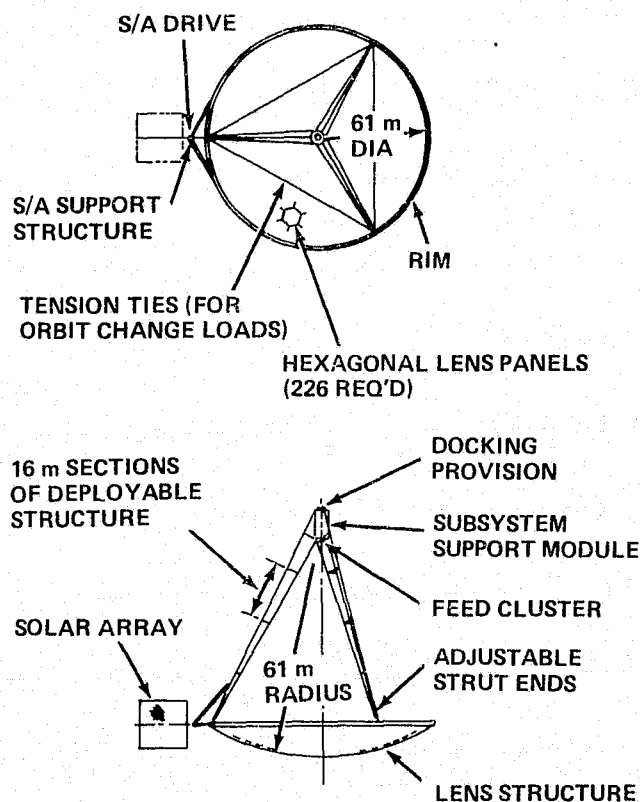
Figure 3-13 OCDA/Radiometer Arrangement

The antenna components, core module, circumferentials, reflector mesh and contour control devices, in addition to the rib fabrication module and assembly fixture, are Shuttle delivered to the OCDA. The radial ribs are fabricated on-site and an OCDA boom mounted cherry picker is used for the construction of the antenna.

3.3.2 Multi-Beam Communications Antenna

The multi-beam communications antenna, shown in Figure 3-15 being assembled at the OCDA, is a large (61-m diameter) bootlace lens satellite that is ultimately operated in a geostationary orbit to provide low cost communications links in the public sector. The antenna has 256 fixed beams for U.S. high population centers and 16 scanning beams for service of rural areas. The large aperture provides sufficiently high gain to significantly reduce cost of the ground transmitter and receiver antenna.

This antenna, as is shown in Figure 3-14, is configured for orbital assembly by using a maximum amount of prepackaged components that have been assembled and checked on the ground. The lens aperture contains multiple panels that are hexagonal and connected together to form a spherical shape. Each panel is 4.5 m in diameter for convenient packaging in the Shuttle. The panels are assembled with an interface connection plate and three fasteners. A rim is utilized after assembly of the hex panels to stiffen the aperture and to provide attachment points for the feed support structure. The rim is a preformed member made of thin material that is elastically flattened and rolled into a convenient stowage package.



ELECTRICAL POWER REQUIREMENTS

	POWER (WATTS)
COMMUNICATIONS ELECTRONICS	43,785
TT&C	65
FLIGHT CONTROL	50
PROPULSION	20
THERMAL CONTROL	40
ELECTRICAL POWER & INTEGRATION	20
TOTAL	43,980

MASS PROPERTIES

	LBM	Kg
• ANTENNA APERTURE		
– LENS PANELS	19,460	8,825
– APERTURE RIM	2,063	936
• FEED SUPPORT STRUCTURE	1,875	850
• SUBSYSTEM MODULE		
– STRUCTURE	125	57
– FEED/DIPLEXER ASSEMBLY	156	71
– COMMUNICATIONS ELECTRONICS	563	255
– TT&C	37	17
– FLIGHT CONTROL	147	67
– PROPULSION	87	39
– THERMAL CONTROL	63	29
– ELECTRICAL POWER & INTEGRATION	2,125	964
• SOLAR ARRAY	750	340
• PROPELLANT	280	127
TOTAL	27,731	12,577

Figure 3-14 61-m Multi-Beam Communications Antenna Configuration

The lens panels are non-metallic honeycomb sandwich construction with many small dipoles on the feed side, and dipoles and a conductive layer (ground plane) on the transmit side. Delay lines, made of flexible dielectric material with deposited conductive paths, provide a passive means of phase shifting the signal to form the proper transmitted wave front.

The feed to aperture support structure are deployable sections that are mated end-to-end in a fashion similar to that used to assemble the OCDA rotating boom. The feed and antenna subsystems are delivered fully assembled.

The construction procedures are illustrated in Figure 3-15. Three to four Shuttle flights are required. The first flight delivers the bulk of the antenna panels and a lens holding fixture that is mounted to the corner of the OCDA platform. The fixture rotates to allow convenient access to the antenna during assembly of the hex panels. After completion of the panel assembly, the rim is deployed and mounted to the aperture. Another fixture, delivered on the second flight, is mounted adjacent to the OCDA mast and used to support the antenna feed. The aperture-to-feed support is then assembled. After assembly, the antenna is positioned for testing using a free-flying mapping satellite.

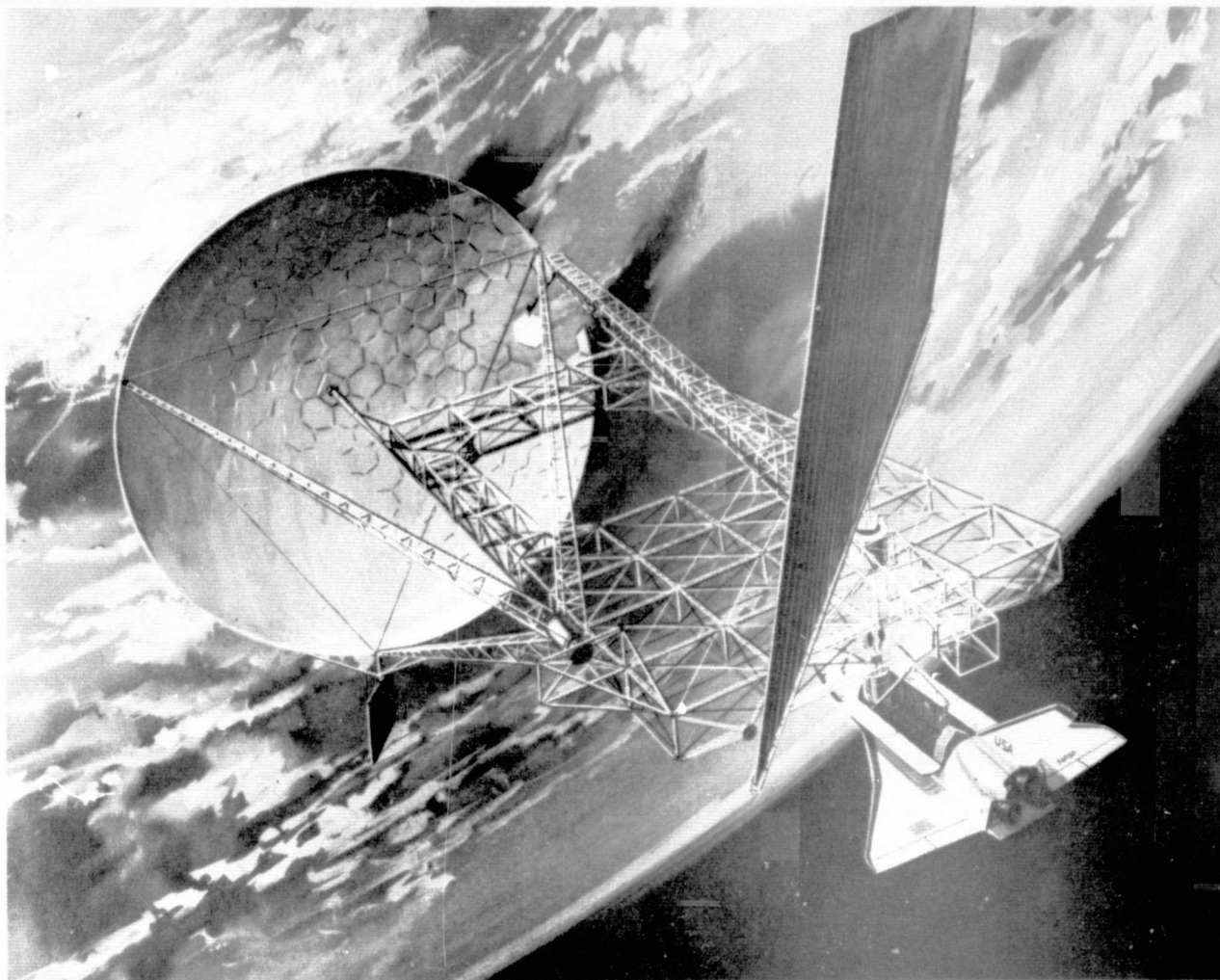


Figure 3-15 Multi-Beam Communications Antenna Construction

3.4 FOLLOW-ON PROGRAM SUMMARY

3.4.1 Programs 1 and 2

An assessment of the mission suitability (demonstration objectives met) of Program Scenarios 1 and 2 was made using the 72 demonstration objectives identified in the basic study as the basis for comparison. Program 1 meets more objectives than does Program 2 mainly because of the size of the Program 1 pilot plant end-item relative to the size of the element demonstrations being performed in Program 2, and provides a key power from space to ground demonstration.

The major objectives not met in both programs are those associated with large antennas and solar thermal power satellites. Demonstration objectives that require a geosynchronous orbit location are also not met. These include those associated with testing microwave transmission systems and solar array high voltage characteristics.

The feasibility of transporting the 2 MW pilot plant to geosynchronous orbit should be studied to facilitate an increase in Program 1 mission suitability. The potential uses of the OCDA transported to geosynchronous orbit should also be studied and mission suitability reassessed.

The cost of Program 1 is 35% higher than Program 2 with the development and unit cost of the 2 mw solar array being the largest contributor to the cost difference. The benefits of a program in terms of objectives met, may well offset the higher cost. A breakdown in costs are shown in Figure 3-16. The cost of the basic OCDA is higher in the case of Program 2, reflecting the requirement for a 471 kW solar array rather than the 290 kW solar array needed in Program 1. The mission equipment costs in Program 1 are higher, due primarily to the cost of the 2 MW solar array.

	SCENARIO 1	SCENARIO 2
BASIC OCDA COST, \$M	337	447
MISSION EQUIP COST, \$M	1202	654
TRANSPORTATION, \$M	312	273
TOTAL, \$M	1856	1374
% OBJECTIVES MET (SPS PHOTOVOLTAIC)	76	63

NOTES:

- 1977 \$
- BASIC OCDA & MISSION EQUIPMENT COSTS
INCLUDE DDT&E & UNIT COSTS

Figure 3-16 Cost Summary—Programs 1 and 2

A summary of crew manhours required to set up and conduct follow-on activities for Program Scenarios 1 and 2 is presented in Figure 3-17. In all missions studied, sufficient crew time is available to conduct the mission. Many activities require more than seven days for completion (i.e., Missions 5 and 7 in Program Scenario 1 need more than one Shuttle flight for logistics purposes and do not stress crew needs). Others, like the linear waveguide experiment (Mission 2 in Program Scenarios 1 and 2) may require a slight extension of Shuttle stay time.

The analysis of Program Scenarios 1 and 2 indicates that the platform area should be increased as well as the length of the rotating boom relative to the baseline defined in Part I of the study. A 290 kW power source is required for Program 1. The Program 2 requirement would be 471 kW. The platform should be designed to support a peak mass of materials and equipments of approximately 65,000 kg.

3.4.2 Program 3 – Antenna Construction

A construction program centered around the assembly of a large antenna can be expected to be as costly as the programs required to advance SPS technologies. Programs 1 and 2 alone were estimated to be \$1.4 to \$1.9B. The complexity and need to achieve tight contour accuracies contributes to the high cost (\$1.2B) of the large antenna programs as summarized by the crew manhours needed for construction in Figure 3-18. The radiometer, in particular, required eight 7-day Shuttle flight for construction. If additional habitation is provided in the form of a spacelab module, the radiometer could be constructed in two 30-day missions.

The antenna construction missions have no significant impact on the basic OCDA general arrangement or power level. The key dimensional requirement was found to be the length of the rotating boom. The 108 m length was found to be adequate, for construction operations. The major power requirement was found to be lighting. Approximately 40 kW of power was considered the minimum level needed for dark side of the orbit construction activities. A delineation of these lighting requirements can be found in Volume II.

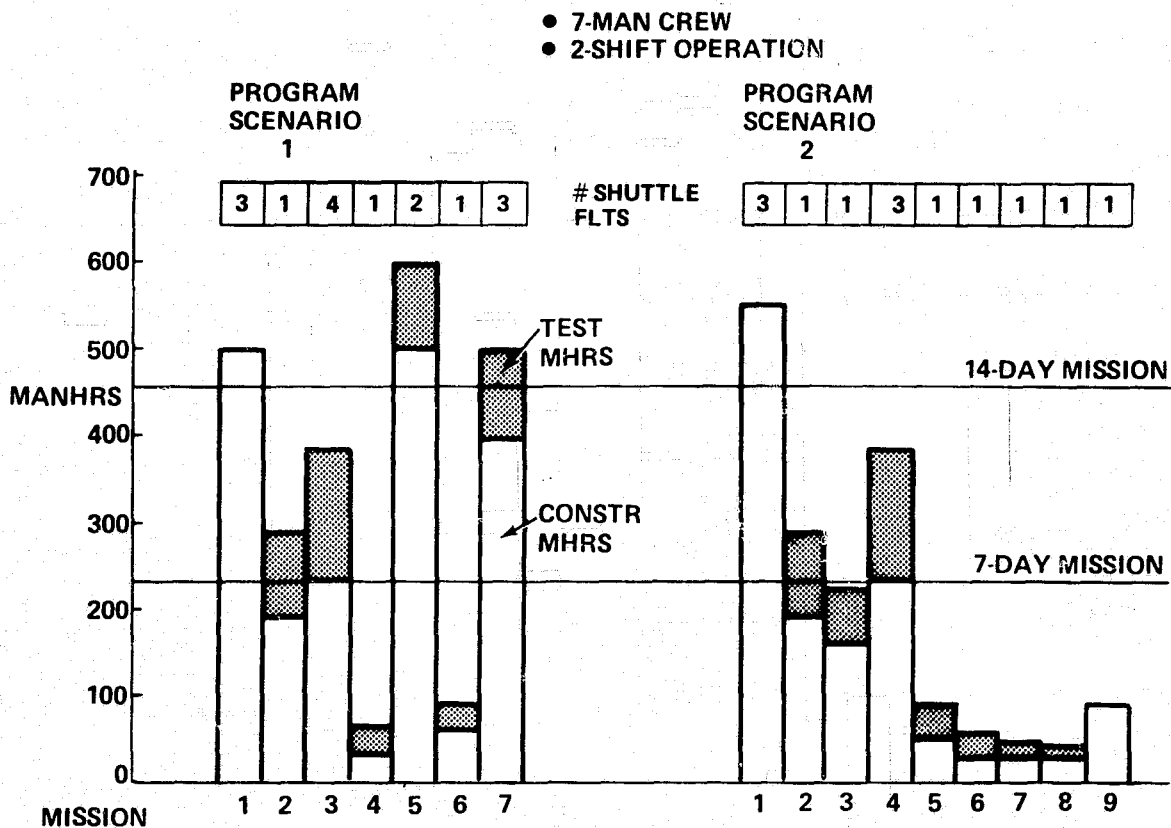


Figure 3-17 Crew Manhour Requirements

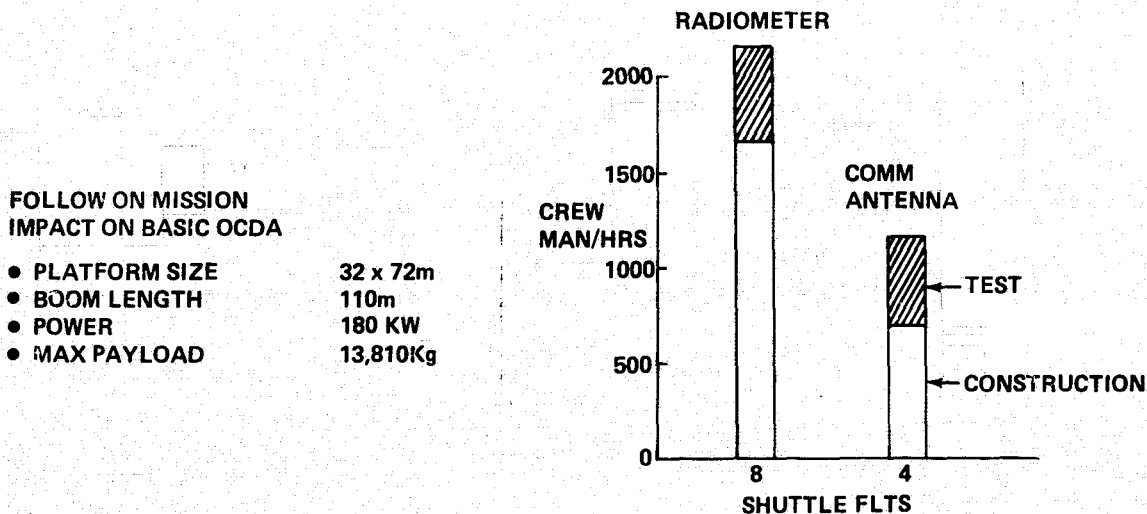


Figure 3-18 Summary of Requirements

Section 4

DESIGN REQUIREMENTS

4.1 LAYOUT AND EQUIPMENT

The configuration layout requirements for the follow-on programs that emphasized SPS technology advancement (Programs 1 and 2) and large antenna construction (Program 3) result in the plan-form needs summarized in Figure 4-1. Both Programs 1 and 2 require larger platform sizes than the baseline to accommodate the 20-m deep truss girder fabrication equipments. Both require a platform width of at least 40 m, and Program 1 requires a platform length of 96 m to accommodate the added fixtures needed to build the 2 MW solar array. The baseline platform size is adequate for constructing the 100-m diameter radiometer and the 61-m diameter multi-beam communications antenna. The antenna construction, however, requires a rotation boom length that is at least as long as the baseline 108 m.

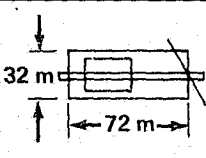
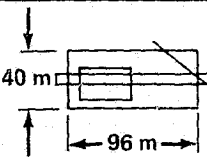
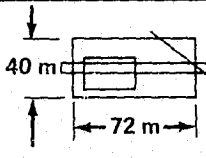
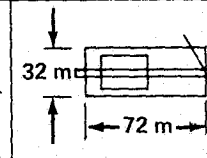
	BASELINE OCDA	PROGRAM 1	PROGRAM 2	PROGRAM 3
REQUIREMENT				
PLATFORM DIMENSIONS				
• LENGTH, m	72	96	72	72
• WIDTH, m	32	40	40	32
• DEPTH, m	4	4	4	4
BOOM LENGTH, m	108	116	108	108
MASS, Kg (DRY)	28,958	37,261	31,040	28,958

Figure 4-1 Layout Requirements

The equipments needed for assembling the 2 MW solar array are shown in Figure 4-2. These equipments include a fixture that supports seven 1-m deep beam fabrication modules. Six are used to fabricate the 20-m deep truss girder and the seventh is used to fabricate the lateral beam members that "stitch" the second 20-m beam to the first, which is supported in the "holding fixture" shown on the lower left portion of the platform in Figure 4-2.

During 20-m beam assembly operations, the boom traveler is used for transporting material from the Orbiter payload bay to the boom mounted cherry picker. This cherry picker services the fabrication and conductor modules adjacent to the platform and hands over material to the track mounted cherry pickers for servicing the other fabrication modules. The track cherry pickers will be in constant use during assembly of the solar collector. They will connect the solar blanket electrical cables to the main power line conductors and monitor the fabrication module output. The assembly operations duplicate many of those planned for the full size photovoltaic SPS. Construction should continue at an average rate of 1 ft/min until the 369 m long solar collector is completed.

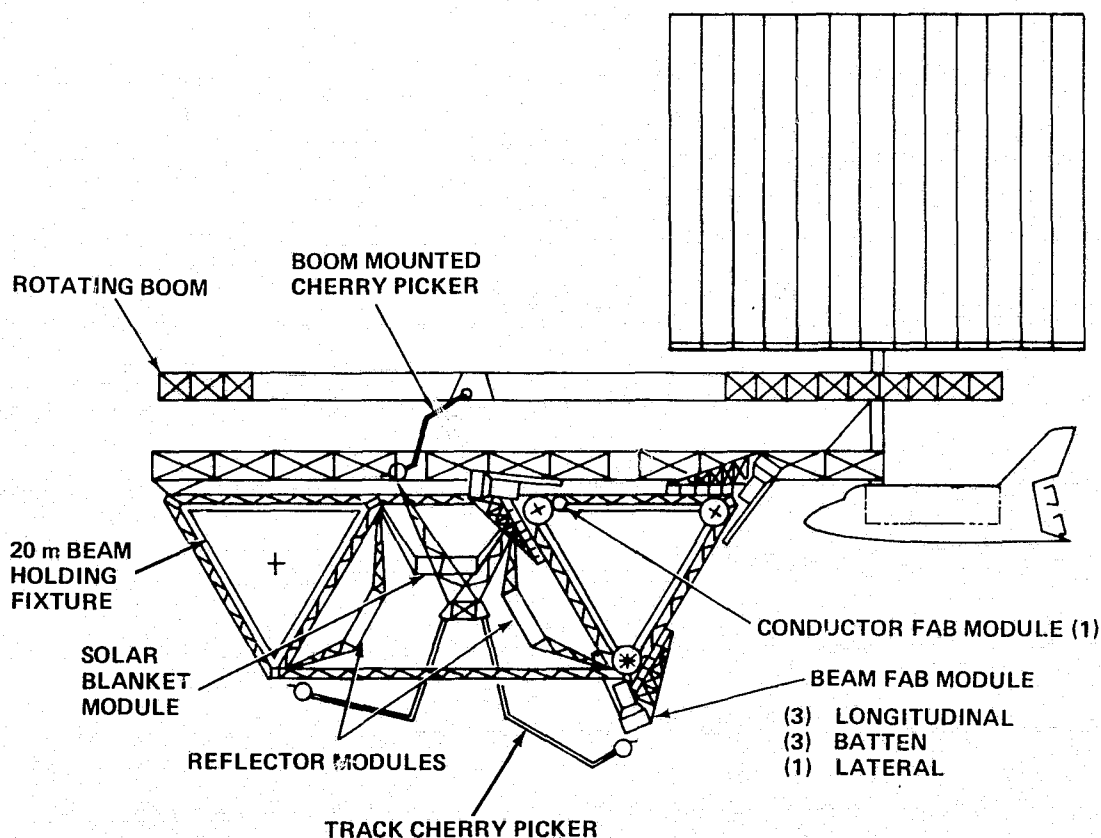


Figure 4-2 2 MW Solar Array Fabrication Equipments

A key piece of construction equipment not included in the baseline inventory is the cherry picker (Figure 4-3). The intricate construction operations required for assembling the linear waveguide to the rotating boom, the square transmit antenna, the large radiometer, and the communications antenna tend to require a crewman located close to the assembly site while operating a manipulator. The cherry picker concept shown in Figure 4-3 permits the crewman to work the manipulator within visual sight of the work area. The across the board utility of this equipment suggests that it should be part of the baseline OCDA equipment, rather than mission peculiar to a given follow-on activity. The cherry picker work station may be configured as a pressurized, shirt sleeve environment bubble or a suited (EVA) operator work platform (open or closed). Each configuration has its advantages and disadvantages and is independent of the basic utility of a manned manipulator. For the purpose of costing, the pressurized bubble was used.

4.2 ELECTRICAL POWER

The basic OCDA power requirements for housekeeping and Shuttle support are shown in Figure 4-4 in terms of OCDA solar array power at the slip ring. Approximately 19 kW average power is required by the OCDA to run subsystems, construction support equipments, and the ion propulsion devices. Requirements for energy storage adds another 15 kW for a total requirement at the slip ring of 33.9 kW. The OCDA support requirement for the Shuttle is to provide 20 kW average power. This equates to 35.6 kW at the OCDA slip ring. The baseline OCDA with a 250 kW solar array would have approximately 90 kW average power for mission activities at 200 Vdc.

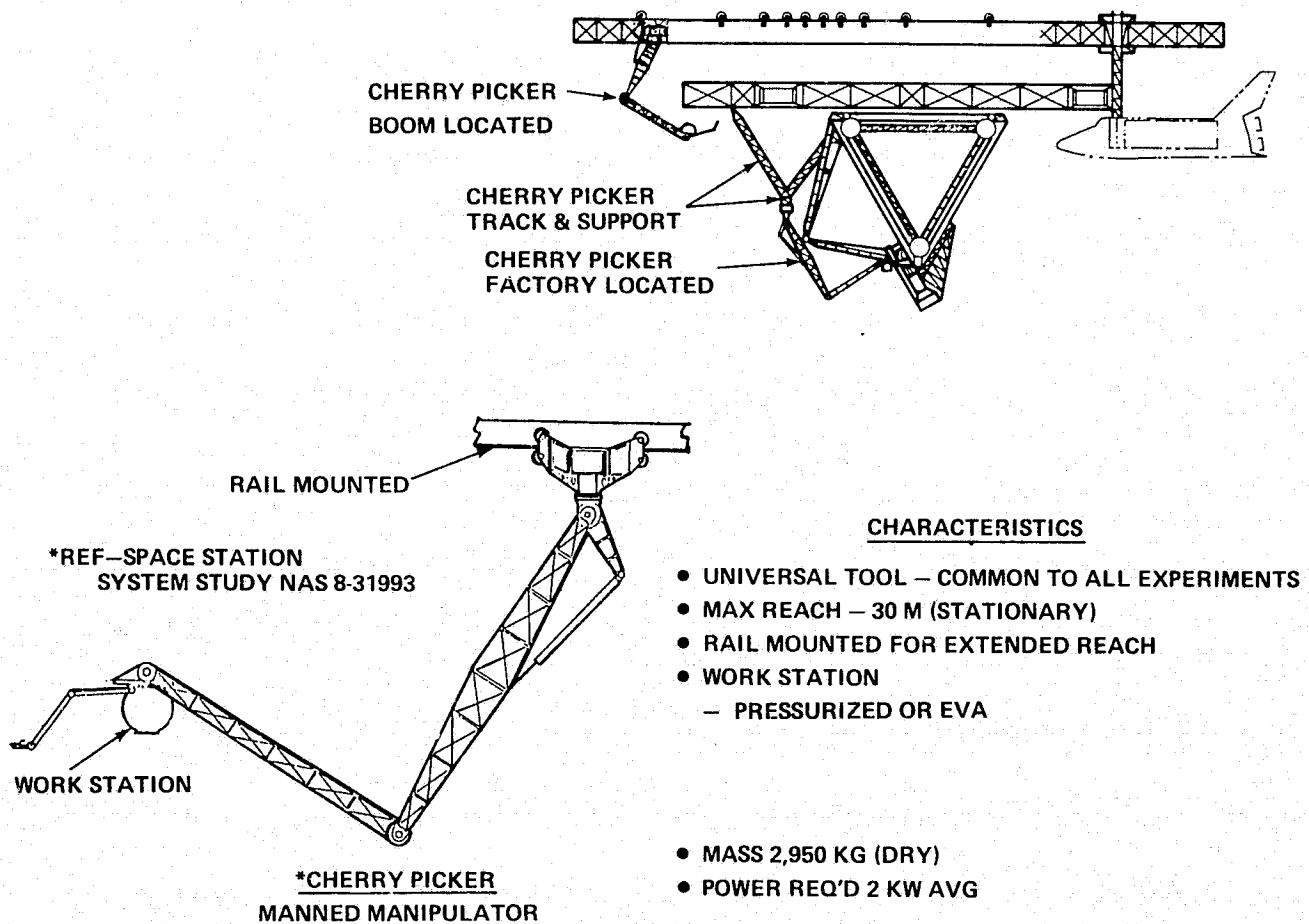


Figure 4-3 Cherry Picker—Manned Manipulator

ON-BOARD		SHUTTLE SUPPORT	
HOUSEKEEPING @ 28 V	1.10 KW	TOTAL REQD STORAGE RECHG	20.0 KW 15.6 KW
LOSSES	0.23 KW		
SUPPORT EQPT	7.25 KW		
LOSSES	0.63 KW		
ORBITKEEPING	8.33 KW		
LOSSES	1.42 KW		
TOTAL EQUIV. LOAD	18.96 KW		
STORAGE RECHG	14.94 KW		
TOTAL @ SLIP RINGS	33.9 KW		35.6 KW

Figure 4-4 Baseline OCDA Electric Power Requirements Without Experiments

The study of follow-on missions indicates that the 250 kW OCDA solar array may not be adequate. Figure 4-5 summarizes the major power requirements. The 250 kW was found adequate to perform construction operations, but is too low to conduct SPS related microwave testing. In Program 1 the microwave linear array mission requires an array rated at 290 kW (BOL). The solar array requirements increase to 471 kW for the Program 2 in which the linear array test is performed with klystrons. The Program 3 power requirements of 180 kW is needed because the assembly operations during the dark period of the orbit require an estimated 40 kW for lighting.

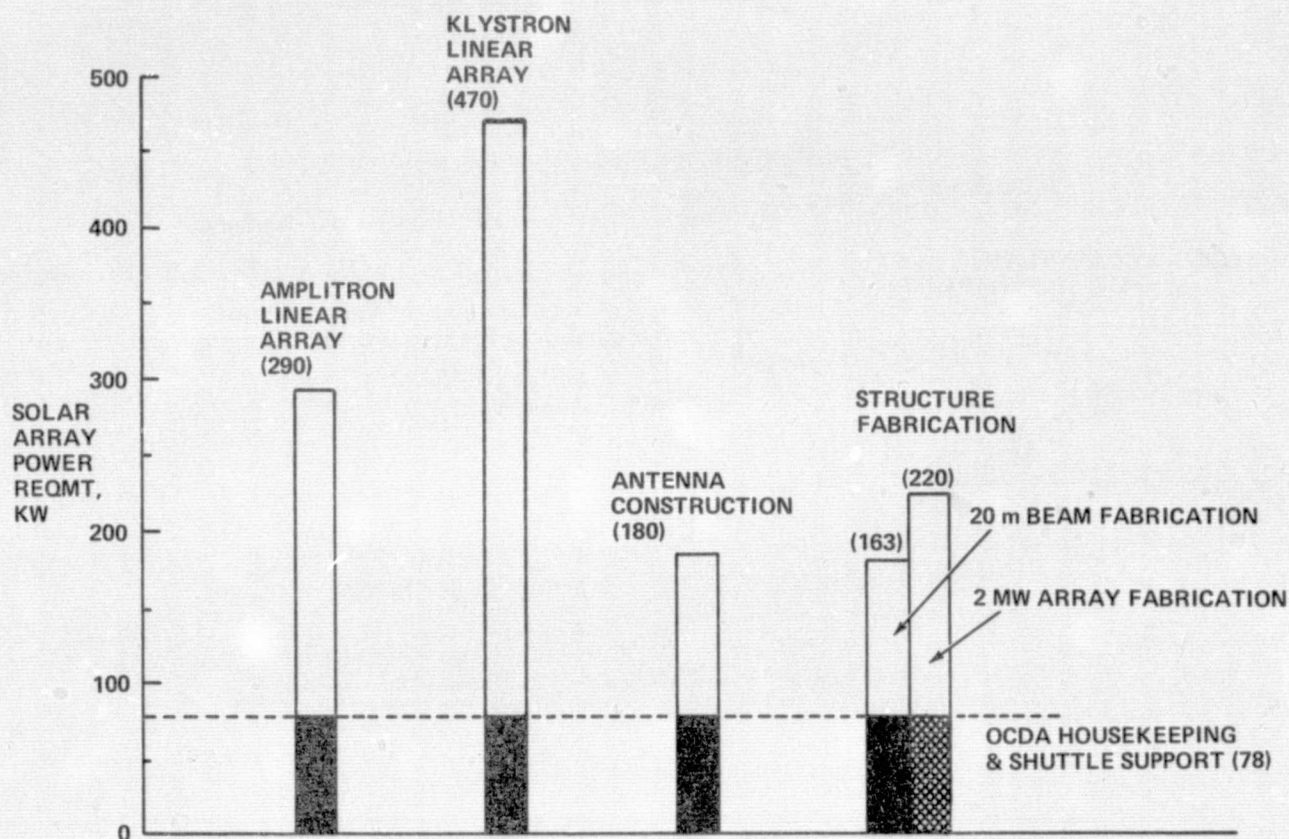


Figure 4-5 OCDA Solar Array Power Requirements

The power requirements for conducting the 20-m beam fabrication experiments in Programs 1 and 2 are also relatively high. Even with modest lighting, which illuminates a 15 sq m area around the apex of the beam being assembled at 10 ft-candles, and 1 ft-candle general illumination for safety, the lighting requirements are as high as 75 kW. Power requirements also vary with the number and speed of the fabrication modules used, and could push total mission peculiar power requirements as high as 113 kW. When added to OCDA housekeeping power and shuttle support power, this can push the solar array requirement to 306 kW.

4.3 ORBITKEEPING AND ATTITUDE CONTROL

The orbit-keeping requirements impact on the baseline OCDA is summarized in Figure 4-6. The Shuttle capability for delivery of cargo to circular orbits as a function of orbit altitude and inclination are shown. The OCDA can be placed in an orbit between 350 km and 400 km, and inclination between 28.5°

and 45° and still be within the Shuttle payload limits for delivering the materials and orbit-keeping propellants for one year's operation. The fully deployed solar array is the dominant air drag effect, resulting in an orbit-keeping propellant requirement of 216 kg per year at an altitude of 350 km using ion propulsion ($I_{sp} = 6000$ sec). The impact of the follow-on missions on orbit-keeping propellant requirements were not assessed.

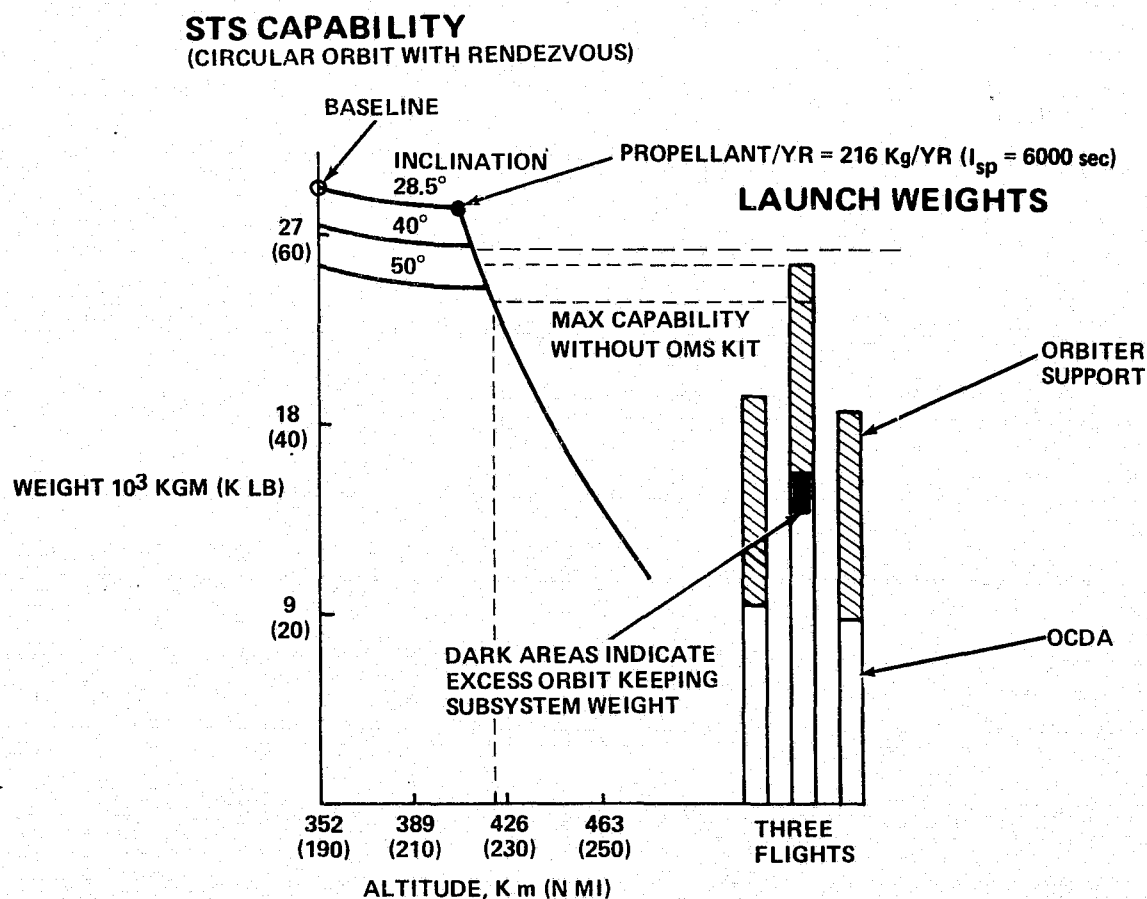


Figure 4-6 OCDA Launch Envelope

The baseline OCDA attitude control disturbance torques and propellant requirements are summarized in Figure 4-7. These calculations assume that the OCDA platform is aligned along the local vertical resulting in a 17° offset between the control axis and the inertia principle axis. This results in conservative propellant consumption estimates of over 100 kg/day using a monopropellant jet system. If the control system steers the inertia principle axis to within 1° of the vertical, propellant consumption can be reduced to as low as 20 lb/day for controlling mainly aerodynamic disturbances.

	TORQUES (FT-LBS)									
	WITH ORBITER						WITHOUT ORBITER			
	T_x		T_y		T_z		T_x		T_y	
	BIAS	CYCLIC	BIAS	CYCLIC	BIAS	CYCLIC	BIAS	CYCLIC	BIAS	CYCLIC
AERODYNAMIC	0	0	- 5.5	±4.8	21.5	±20.2	-0	0	8.5	± 8.7
GRAVITY GRADIENT	9.0	±5.6	- 8.0	±1.6	1.5	± 0.5	-9.0	±3.5	-2.0	± 2.2
SOLAR PRESSURE	0	±0.4	0	0	0	± 0.4	0	±0.3	0	0
MAGNETIC (UNCOMP)	0.02	0	0	0	0.02	0	0.003	0	0	0
TOTALS	9.0	±6.0	-13.5	±6.4	23.0	±21.1	-9.0	±3.8	6.5	±10.9

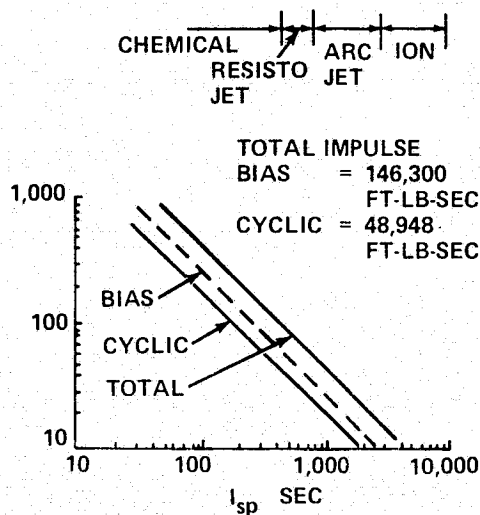
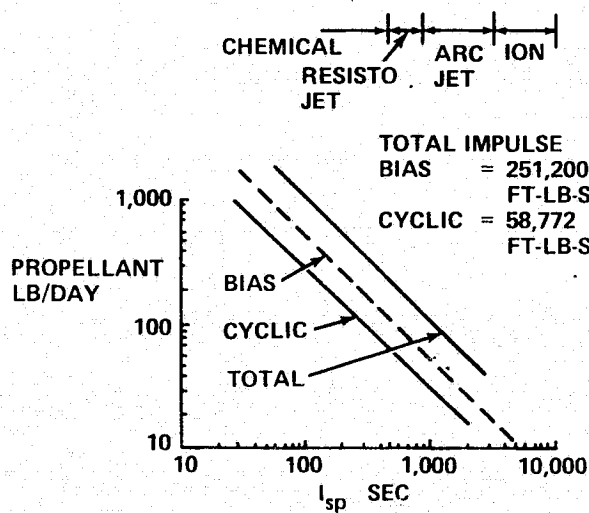


Figure 4-7 Control System Requirements

Section 5

PROGRAMMATICS AND COST

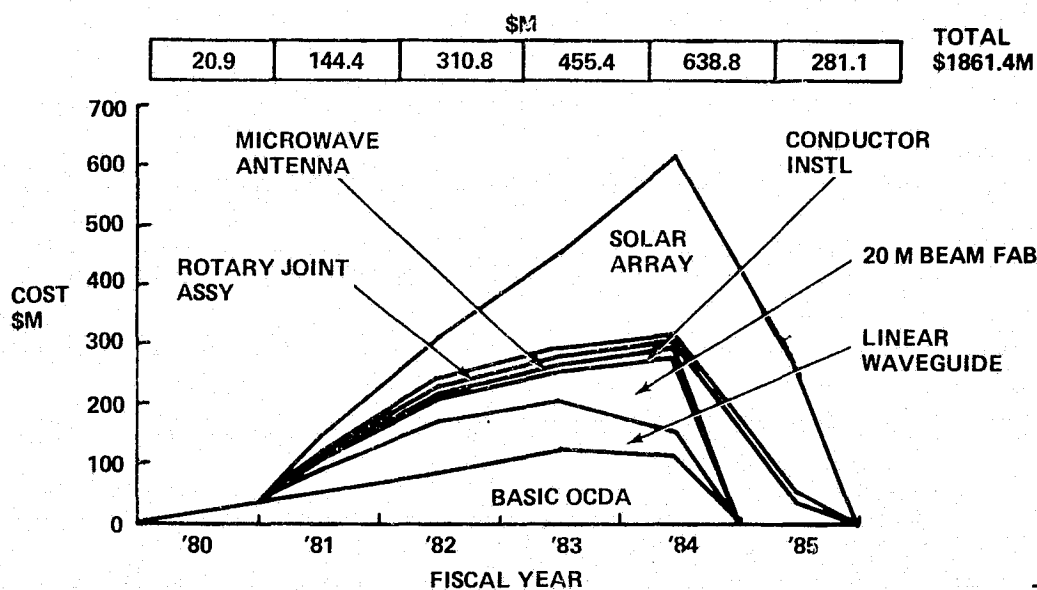
5.1 BASELINE OCDA

A breakdown of the baseline OCDA cost estimate are summarized in Figure 5-1. Total program costs, including \$169M for DDT&E and \$58.5M for three Shuttle flights, is \$390M. Nominal amounts were added for program management, systems engineering and integration, and GSE. Costs have been estimated in 1977 dollars using cost estimating relationships (CERs) and vendor estimates. Costs are estimated to be accurate to within 50%.

The OCDA annual funding requirements are summarized in Figure 5-2. Peak annual funding is estimated to be \$123M occurring in FY 1983.

ELEMENT	COST, \$M	
	DDT&E	1ST UNIT
CORE MODULE/MAST	(13.11)	(18.85)
• STRUCTURE	3.04	.76
• DOCKING RING	0	1.47
• COMM/DATA HDL	.82	2.70
• ELECTRICAL POWER	5.82	8.40
• ACS	3.42	5.53
PLATFORM	(50.62)	(20.74)
• STRUCT/MECH	37.92	9.48
• POWER DISTRIBUTION	3.55	2.21
• PROPULSION	4.14	1.08
• ACS	5.00	5.00
• COMM ANT (WB COMM)	0	.03
• DOCK RINGS (2)	0	2.94
ROTATING BOOM/MANIP .	(41.36)	(17.42)
• STRUCT/MECH	22.64	5.66
• PWR DISTRIBUTION	5.97	3.72
• MANIP/CARRIAGE	0	3.46
• TRAVELLER	4.51	.78
• ROTARY JOINT	8.25	3.80
SOLAR ARRAY	(23.04)	(79.34)
• STRUCT/MECH	.69	1.52
• SOLAR BLKTS/DEPL MECH	18.81	76.69
• PWR DISTRIBUTION	3.54	1.13
TOTAL SUBSYSTEMS	(128.13)	(136.35)
PROGRAM MANAGEMENT	15.36	11.97
SYSTEM ENGR & INTEGRATION	12.68	12.35
GSE	12.81	.90
SUBTOTAL	330.55	
SHUTTLE COSTS	58.5	
TOTAL	389.05	

Figure 5-1 Basic OCDA Costs



MISSION

1. BASIC OCDA
2. LINEAR WAVEGUIDE
3. 20 m BEAM FAB
4. CONDUCTOR INSTL
5. MICROWAVE ANTENNA
6. ROTARY JOINT ASSEMBLY
7. SOLAR ARRAY FAB

y	20.9	51.5	82.0	123.1	118.6	
		33.0	79.2	79.6	46.3	
		15.6	41.5	51.8	118.6	
		3.7	9.4	10.5	23.4	
		5.2	11.5	20.4	19.3	39.0
		6.0	14.7	18.3	18.1	26.5
		29.4	72.6	151.7	294.5	215.6

TOTALS, \$M

396.1
238.0
227.5
57.0
95.4
83.6
763.8

Figure 5-2 Program 1 Annual Funding Requirements

5.2 OCDA FOLLOW-ON PROGRAMS

The annual funding requirement for the three follow-on program scenarios studied are summarized in Figures 5-2 through 5-4. Program Scenario 1, which addresses SPS technology advancement by constructing a 2 MW pilot plant, is expected to cost \$1.85B, including the cost of the OCDA and supporting Shuttle flights. Peak annual funding for this program will be between \$600M and \$700M, including OCDA costs. Program Scenario 2 is estimated to have a total program cost of \$1.4B with a peak annual funding between \$400M and \$500M. Program 2 addresses SPS technology advancement through element size demonstration rather than through constructing end items like the 2 MW pilot plant in Program 1. Program Scenario 3, emphasizes construction of large antenna, and is expected to cost \$1.2B. Two antennas are included in this program, a 100-m diameter radiometer and a 61-m diameter multi-beam communications antenna.

5.3 SUPPORTING RESEARCH AND TECHNOLOGY

An overview of the Supporting Research and Technology (SR&T) programs recommended in support of the OCDA and their relationship to the OCDA Phase C&D projected schedule is shown in Figure 5-5. The schedule breaks down the SR&T effort into systems level studies, subsystem and hardware component development, and simulations required to support OCDA. As indicated on Figure 5-5, the OCDA Phase C&D schedule allows ample time for the completion of the systems and hardware development programs, including the completion of prototype hardware ground tests by the OCDA CDR. Availability of a hard-

ware data base verified through extensive ground tests prior to CDR will facilitate the integration of the findings into the OCDA design. Approximately a year of extensive ground testing of the prototype hardware, preceded by 18 months of design, fabrication and breadboard testing, plus a year for conceptual and systems engineering is allowed in the overall development schedule for most of the support technology. The storage battery development is less than the average because of the current development efforts on NiH and NiCa batteries, which should reduce the OCDA cycle considerably. The design, fabrication and ground test effort required to develop the prototype lighting systems is also projected to be less than the norm.

Simulations will be a very important part of the development cycle. Every piece of prototype hardware and OCDA hardware will be subjected to as extensive a simulation program as possible. Neutral buoyancy and other facilities should be used to develop all of the procedures and techniques required for orbital construction and test operations. The man/machine interface and utilization of the hardware in a simulated environment will provide invaluable design refinements before committing the final hardware to orbital operations.

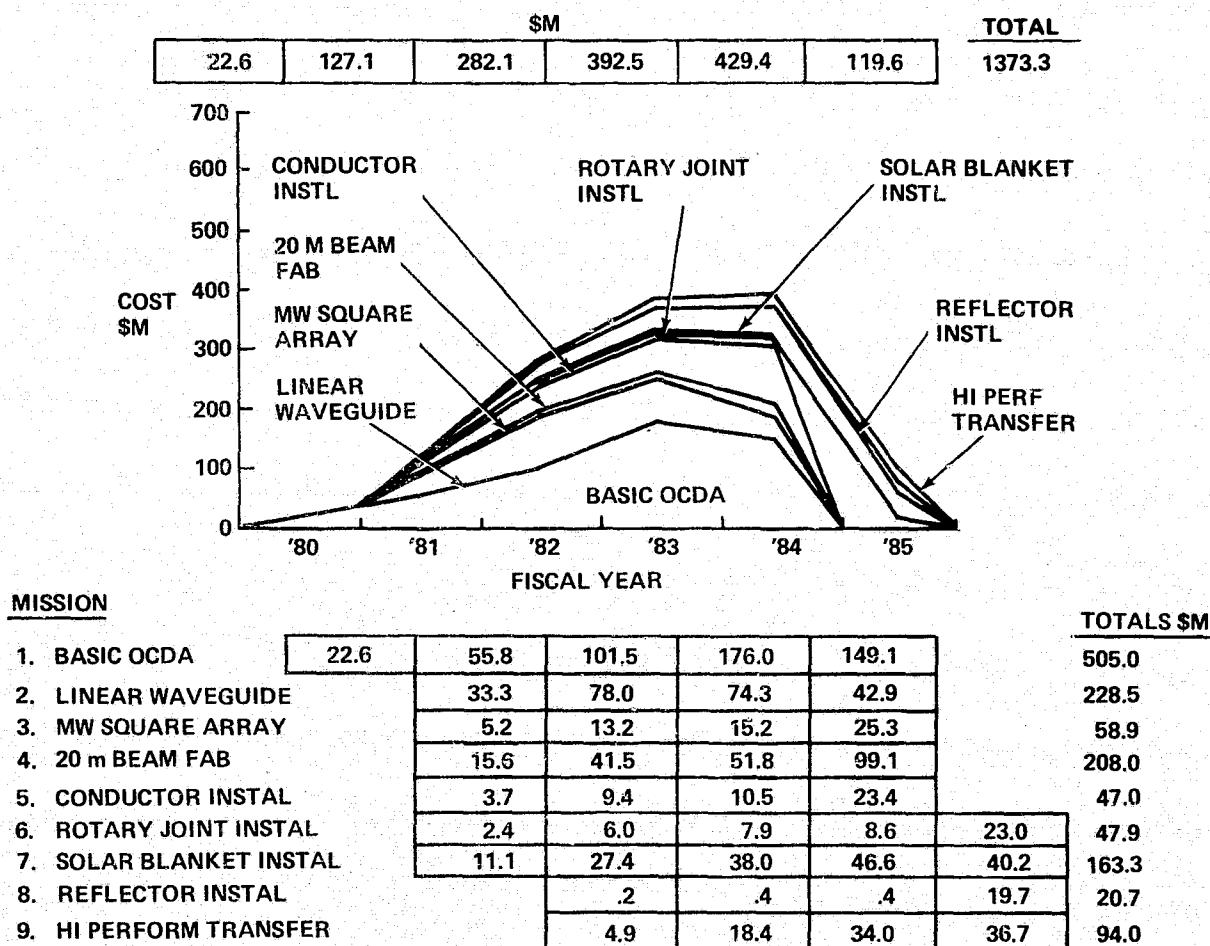


Figure 5-3 Program 2 Annual Funding Requirements

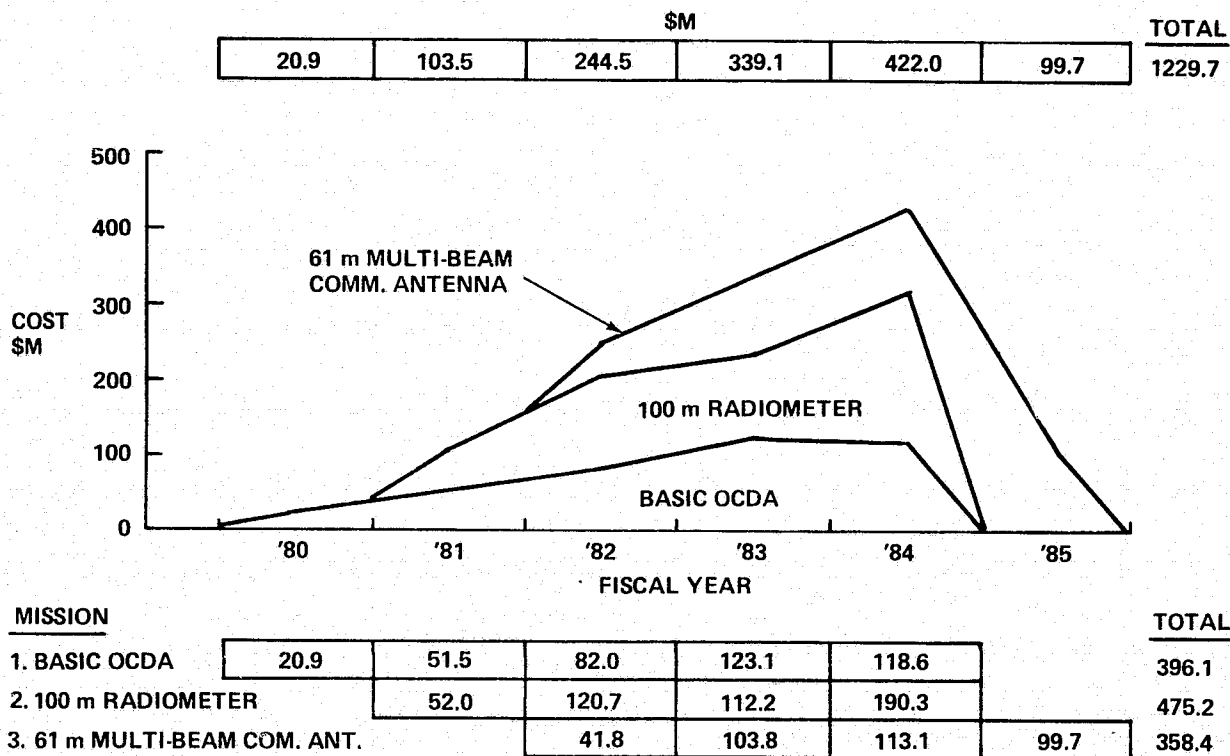


Figure 5-4 Program 3 Annual Funding Requirements

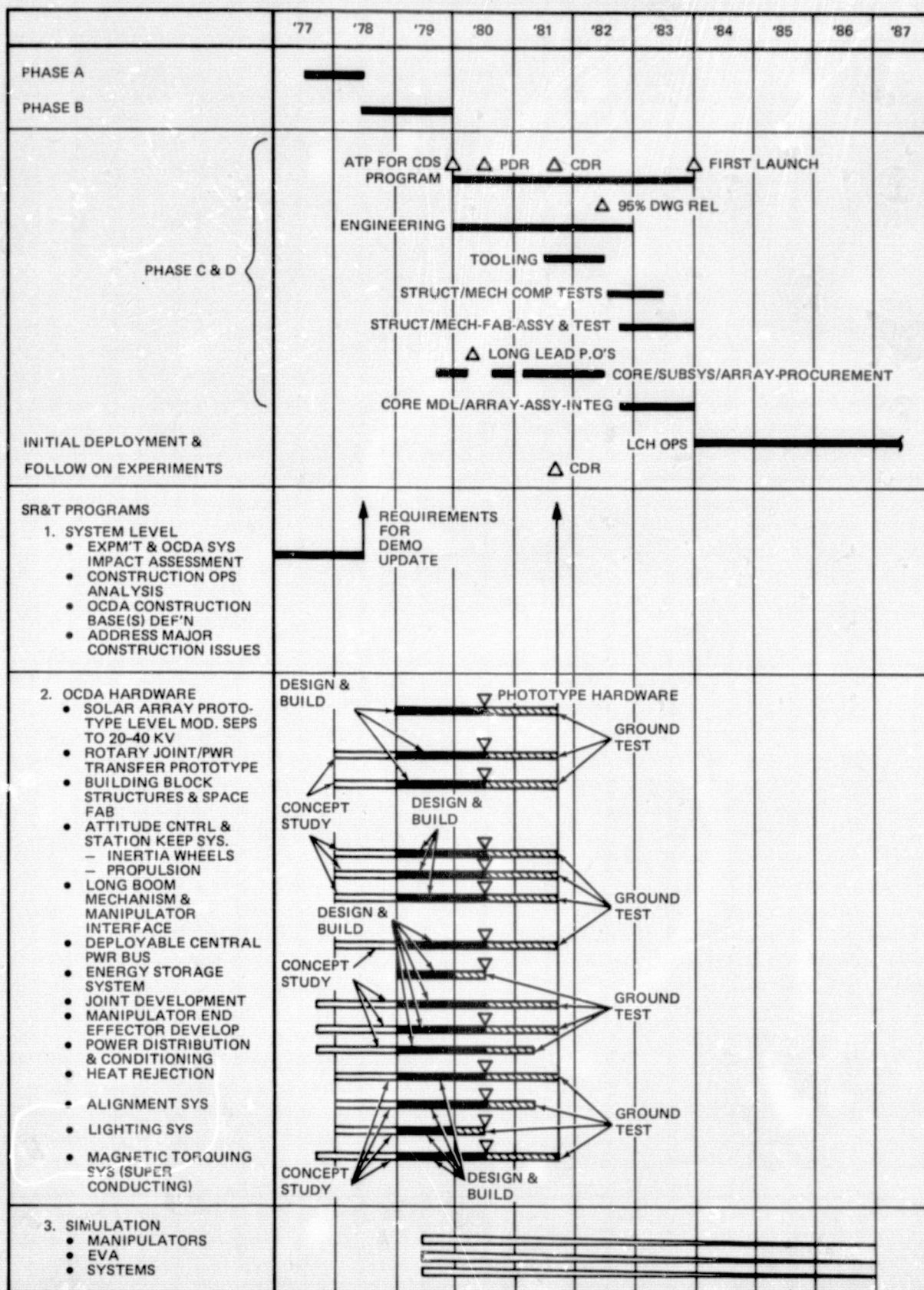


Figure 5-5 OCDA Supporting Technology Requirements

Section 6

STUDY CONCLUSIONS

The objective of this study was to develop an orbit demonstration program that advances technologies by constructing a demonstration article that addresses many of the construction issues associated with future large structures. The construction of a general purpose construction facility in three Shuttle flights met this objective, but also provided more than expected capability to continue the advancement of construction technologies with Shuttle revisits, and to provide the facility of constructing large operational antenna structures.

Five future large structure concepts were identified that embodied the requirements and issues for all anticipated future endeavors. Based on these five representative future concepts, demonstration objectives were formulated and used as the basis for the design of a general purpose construction base that is operated from the Shuttle. The in-orbit assembly of this Orbital Construction Demonstration Article (OCDA) in three Shuttle Flights makes a substantial contribution to technology objectives identified in this study. An alternate approach for demonstrating large structures technologies is the use of Shuttle sortie missions. Although the number of Shuttle flights using sorties or constructing OCDA are comparable, the principal advantage of the OCDA approach is that NASA would have a permanent orbiting facility which can continue to be used to evaluate in-space fabrication operations and personnel productivity, in addition to being used to build operational antennas in the fields of communications and earth resource observation.

The benefits of a Shuttle supported construction base are most apparent from the study of OCDA follow-on activities. A representative "Building Block" for an ultimate Solar Power Satellite, for example, is a large 20-m truss girder that must be fabricated at a rate of 0.3 m/min, using two or three crewmen. It was found that a large platform, in the neighborhood of 40 m x 72 m, would be needed to support the large fixtures and equipments for simulating the synchronized operations for constructing this basic structural element. A large OCDA power source was also found necessary to support the construction equipments and to provide adequate lighting for continuous construction operations.

The need for adequate lighting was also apparent from the assessment of the intricate construction operations needed for antenna assembly. To provide a minimum 15 ft-candles in the immediate construction area and 1 ft-candle general coverage of a single gore (for safety) would require 35 kW average power. This lighting requirement, when added to the power required for construction equipment, OCDA house-keeping and Shuttle support, establishes a need for a minimum 180 kW solar array.

Installation of subsystem elements, within a large space structure was found to be a more difficult task than fabricating the basic structure itself. The OCDA was found to be of significant benefit as a facility for demonstrating and evaluating synchronized installation of large area solar blankets, power bus systems, and data management networks with the primary structure. These operations alone can be on a large enough scale to provide confidence in the ultimate assembly procedure.

The utility of the OCDA can also be expanded to encompass in-orbit microwave testing related to Solar Power Systems. An increase in solar array power from the 250 kW needed for construction to 290 kW would capture the requirements for microwave system phase control testing using an amplitron fitted linear array. An increase in power to 470 kW would provide the capability to perform similar linear array phase control tests using klystrons.

This study has shown the substantial utility and benefit of a small, general purpose in-orbit construction facility. It is recommended, therefore, that the OCDA concept be seriously considered in NASA's planning for advancing large structures technologies and providing an initial space construction capability. Near-term planning should:

- Initiate the studies to define system requirements to meet schedules as shown in Figure 6-1.
- Target for a 1984 IOC to support key programmatic decisions in the 1987 time frame on ultra large structures

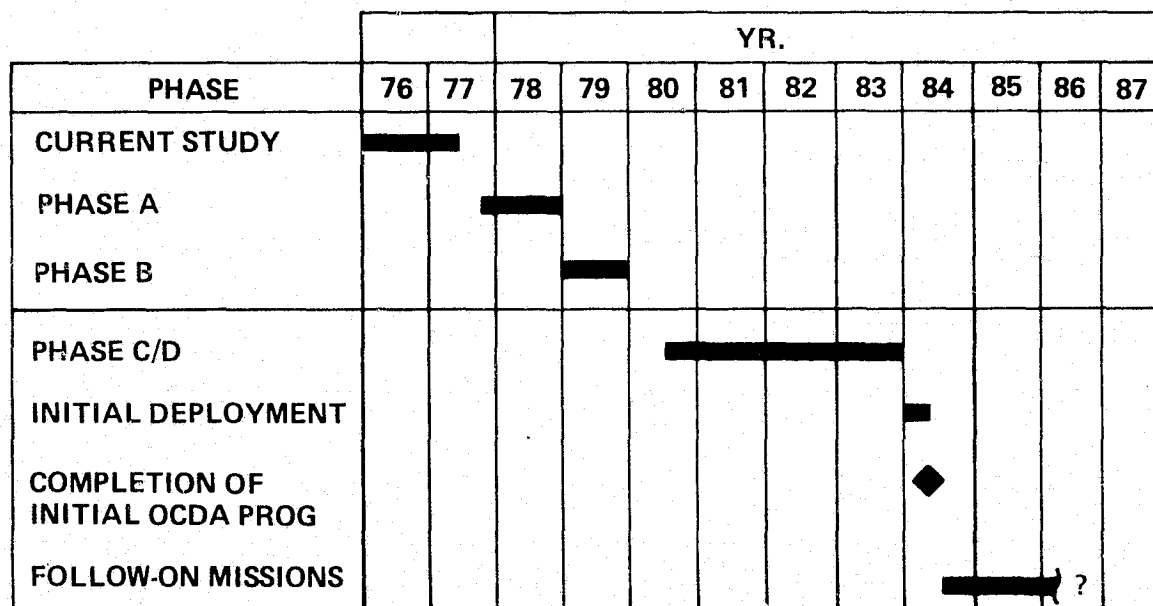


Figure 6-1 OCDA Program Planning Schedule